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A STUDY OF BICYCLE/MOTOR-VEHICLE ACCIDENTS: IDENTIFICATION OF PROBLEM TYPES AND COUNTERMEASURE APPROACHES

U.S. Department of Transportation

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VOLUME I

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16. Abstract

The purpose of this study was to determine the causes of bicycle/motor-vehicle accidents and to use data on accident causation to identify potential countermeasure approaches. Data were collected by interviews and on-site investigations for 753 non-fatal accidents and 166 fatal accidents. The sampling areas, each consisting of several contiguous counties, were located in California, Colorado, Florida, and Michigan. In addition to an analysis of descriptive data, accident cases were classified into "problem types" based upon traffic context, accident causes, and target groups. A total of 36 unique problem types were identified; the ten most frequent problem types accounted for 67% of the fatal cases and 64% of the non-fatal cases. The results of the analyses of descriptive data are discussed and the distinguishing characteristics of each problem type are described. Potential countermeasure approaches are suggested for each problem type.

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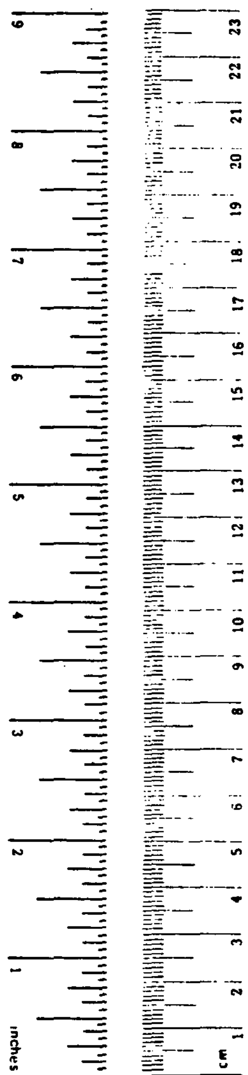
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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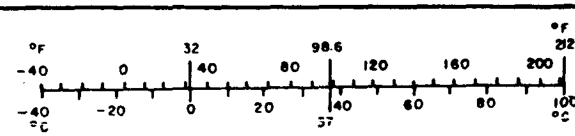

PREFACE

This report documents the work performed under Contract DOT-HS-4-00982 and documents the major findings and conclusions resulting from the work. The three volumes of the report have been organized to meet the needs of a variety of users. Volume 1--the main body of the report--begins with an Executive Summary which will satisfy the needs of the reader who requires only a general understanding of the research procedures and findings. The remaining sections of Volume 1 contain a detailed description of the project objectives, methods, findings, conclusions, and recommendations. It is expected that Volume 1 will satisfy the needs of most users.

The second volume contains specimens of the various instruction manuals, questionnaires, and other data-collection instruments used in this study. Volume 2 also contains a number of data tables which support the various graphs and summary tables presented in Volume 1. Thus, Volume 2 is a reference document that would be useful only to persons who wish to examine the data-collection instruments first hand or who wish to examine the data at a more detailed level than that presented in Volume 1.

Volume 3 is a coding index which describes the manner in which each data item was encoded. This volume of the report would be useful only to persons who have access to the raw-data file and wish to use it to perform additional analyses.

ACKNOWLEDGMENTS

Because of the nature of this project, its completion required the support and cooperation of many persons. Dr. Alfred Farina, Office of Driver and Pedestrian Research, National Highway Taffic Safety Administration, served as Contract Technical Monitor for the project. Dr. Farina provided valuable technical counsel at critical stages of the project and provided encouragement during difficult periods. The authors take this opportunity to express their gratitude to Dr. Farina for his continued support throughout the term of this project.

The Field Investigators who collected the data for this project deserve special thanks. They spent many long hours collecting on-site data and conducting the interviews, often under adverse conditions. The authors acknowledge the important contributions of the following Field Investigators: Vella Buchanan, Kathleen Curtin, Ruth Dunlap, Winona Ferguson, Betty Hoffman, Andrea Meier, LaVaughn Teeters, and Patricia Watson.

Assistance from a number of accident record-keeping agencies was required to identify and obtain copies of traffic accident report forms. The following persons deserve special thanks for their help in accomplishing this task: Cdr. Robert A. Bieber, California Highway Patrol; Lt. J. M. Roddenberry, Florida Highway Patrol; Mr. Cordell Smith, Colorado Division of Highway Safety; and Sgt. Jack T. Warder, Michigan State Police.

Mrs. Jean Olsen and Mrs. Nadine McCollim, both members of the Anacapa staff, made important contributions to virtually every phase of this project. The completion of the project would have been far more difficult without their competent and enthusiastic support.

Unfortunately, it is impossible to acknowledge by name the hundreds of bicyclists, motorists, and witnesses who welcomed the Field Investigators into their homes and spent a substantial amount of time discussing a traumatic experience they would have preferred to have forgotten. All who are concerned with promoting bicycle safety owe a very special debt to these individuals.

ADDENDUM

This research report on bicycle/motor-vehicle accidents has, as its major product, the identification of a set of problem types or recurring accident situations, each of which is a relatively well-defined pattern of causal and descriptive factors. The classification system used in this report results in a rather large number of problem types which are valid descriptions of accident circumstances. It is anticipated that NHTSA would review these identified accident situations in light of other research activities and results, and may merge or recombine certain of the categories so as to reduce the number of "targets" at which future R&D would be directed. The classification structure presented in this report was designed with this possibility in mind.

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SECTION I
EXECUTIVE SUMMARY

Accidents involving a bicycle and a motor vehicle represent an important problem in most communities within the United States. Each year since 1972, about 1,000 fatal and 40,000 non-fatal accidents have been reported to the police. Moreover, it is estimated that an additional 40,000 injury-producing bicycle/motor-vehicle accidents go unreported each year.

PROJECT OBJECTIVES

The general objectives of this project were to compile data on the causes of bicycle/motor-vehicle accidents and to use the data to identify countermeasure approaches that have the potential for reducing the number of accidents of this kind. The project was national in scope and encompassed both urban and rural accidents.

METHODOLOGY

Data on bicycle/motor-vehicle accidents were collected in four sampling areas in the United States. The sampling areas were selected to provide maximum coverage of the characteristics of the bicycling population and the environmental conditions in which they ride. The sampling areas, each consisting of several contiguous counties, were located in California (Los Angeles area), Colorado (Denver/Boulder areas), Florida (Tampa/Orlando areas), and Michigan (Detroit/Flint areas). Within each sampling area, a proportionate sample of non-fatal cases was selected from those occurring during each month of calendar year 1975; an attempt was made to select equal numbers of urban and rural accidents at each sampling area. A non-fatal case was rejected from the sample if it was an unwitnessed hit-run accident or if both of the involved operators refused to be interviewed. Because of the small number of fatal accidents that occurred within each sampling area, none were rejected from the sample. Data were compiled on 166 fatal accidents and 753 non-fatal accidents--919 cases in all.

A conceptual model of the accident-generation process was used in defining the data requirements for this study. This model focused on the sequence of functions and events preceding the accident and the factors that influenced the function-event sequence. Data on each accident case in the sample were compiled by trained Field Investigators. Following a highly structured data-collection procedure, Field Investigators compiled and recorded data from several sources, including: the official traffic accident report, observations and measurements taken at the accident site, and detailed interviews with the vehicle operators and persons who witnessed the accident. A structured questionnaire and a detailed scale-drawing of the accident site were used to conduct the operator interviews.

Some questionnaire items were designed to provide information about the characteristics of the operator, his vehicle, and his trip. However, most items were designed to provide detailed information about the accident-generation process. The interview procedures and instruments were designed to provide a clear notion of the pre-crash path of each vehicle, the function failure of each operator, and the combination of factors that were causally related to the function failures.

After the data forms were cleaned and verified by home-office personnel, the Principal Investigator studied the data for each case and made the final judgment about the function failure for each operator and about the factors that contributed to the function failures. The data were then encoded, punched onto IBM cards, and entered into a computerized data file.

A classification system was developed, and the accident cases were classified into mutually exclusive "problem types." Cases classified into the same problem type exhibited commonality in the following attributes: the traffic context in which the accident occurred, the operators' function failures, and the combination of factors causally related to the function failures.

All data items were analyzed by problem type. In addition, selected descriptive-data items were analyzed for the fatal and non-fatal samples--pooled over problem types. The characteristics of individual problem types and the results of the descriptive-data analyses were examined systematically in an attempt to identify general countermeasure approaches having the potential for reducing the incidence of bicycle/motor-vehicle accidents. The final task was to formulate recommendations about additional research requirements.

RESULTS

Selected findings of the descriptive-data analyses are summarized below along with a brief description of a selected sample of seven problem types. The discussion of the descriptive data is intended to provide the reader with a general understanding of the characteristics of the operator, the accident vehicle, the accident trip, the accident location, and the accident consequences. The problem types selected for discussion are among the most frequently occurring. More importantly, the description of this sample of problem types will provide the reader with an understanding of the range of traffic contexts in which bicycle/motor-vehicle accidents occur, the range of factors that contribute to the accidents, and the range of countermeasure approaches suggested by the study of problem types.

FINDINGS OF DESCRIPTIVE-DATA ANALYSES

Operator Characteristics

Sex. The vehicle operators in the study sample--both bicyclists and motorists--were predominantly males. Furthermore, the proportion of males was greater for the fatal sample than for the non-fatal sample. Seventy-one percent of the non-fatal accidents and 85% of the fatal accidents involved a male *bicyclist*; a male *motorist* was involved in 65% of the non-fatal and 72% of the fatal accidents. It is probable that the over-representation of males is due mainly to a greater amount of exposure for males--particularly male bicyclists.

Age. The sample included bicyclists whose ages varied from four years to over 80 years. Beginning at age four, accident frequency rises steadily to the age of 12 and remains at this high level through the age of 15. Thereafter, accident frequency declines dramatically and remains at a relatively low and constant level for ages beyond 30 years. The absolute frequency of accidents is clearly highest for bicyclists between the ages of 12 and 15 years; bicyclists in this age group accounted for about 37% of the accidents. Even so, half of the bicyclists in the non-fatal sample were older than 14.2 years, and half the bicyclists in the fatal sample were older than 16.4 years of age. Although the age distributions for fatal and non-fatal accidents were similar, fatal accidents were found to be proportionately more frequent than non-fatal accidents among the very young and the very old bicyclists.

The age distribution of the motorists in the study sample was found to be highly similar to the age distribution of motor-vehicle operators involved in all other types of traffic accidents.

Experience. It was found that most bicyclists and motorists were experienced vehicle operators who operated their vehicles regularly. In addition, most operators were driving/riding a vehicle they were thoroughly familiar with at the time the accident occurred. About 95% of the motorists and bicyclists had more than one year's driving experience and routinely operated their vehicles two or more hours each week. Seventy-five percent of the bicyclists and 93% of the motorists reported that they had driven the accident vehicle at least 50 times before the accident occurred; only seven percent of the bicyclists and three percent of the motorists had driven their vehicle fewer than five times before the accident.

Physical/mental condition. With the exception of intoxication, few operators reported that they were suffering from any type of impairment at the time of the accident. It was found that less than one percent of the bicyclists were impaired by alcohol. However, evidence that the motorist had been drinking was found in 3.5% of the non-fatal accidents and 16.9% of the fatal accidents. Alcohol was judged contributory in nearly every case in which it was found present. Evidence of drug use was found only infrequently, but the type of data collected during this study cannot be expected to provide reliable information about the number of operators who were under the influence of drugs when the accident occurred.

Bicyclists' knowledge of the law. For all accidents that resulted from the bicyclist's violation of a traffic law, the bicyclist was questioned in detail about his reasons for violating the law. It was found that the violation was due to ignorance of the law in only one case.

Vehicle Characteristics

Vehicle type. About 54% of all bicyclists in the sample were riding a lightweight bicycle, and 40% were riding a middleweight or standard bicycle; less than six percent of the bicyclists were riding a highrise bicycle. The remaining two percent of the bicyclists were riding an adult tricycle, a child's tricycle, or a customized bicycle. A comparison of the types of bicycles ridden by bicyclists in the accident sample with the types of bicycles ridden by the general population showed that lightweight bicycles are overrepresented in the accident sample and that all other bicycle types are underrepresented. Since lightweight bicycles are ridden more frequently and farther than other types of bicycles, it is probable that the overrepresentation of lightweight bicycles in the accident sample is due mainly to greater exposure. However, because lightweight bicycles can be ridden considerably faster than other types of bicycles, it is possible that the overrepresentation is partly due to a higher accident rate.

It has been hypothesized that wide motor vehicles are involved in bicycle/motor-vehicle accidents proportionately more often than standard-size vehicles. The results of this study showed the opposite to be true. That is, trucks and buses were involved in bicycle/motor-vehicle accidents less often than would be predicted from the numbers of such vehicles that are traveling the roadways. Accident involvement as a function of motor-vehicle type is as follows:

- Passenger car (87%)
- Pickup or van (9%)
- Other truck (2%)
- Motorcycle (2%)
- Bus (<1%)

Vehicle condition. It was found that the majority of bicycles were *not* equipped with all the safety items that experts consider essential for safe riding. For instance, the inventory of lighting equipment showed that 68% were equipped with reflectorized pedals, 47% had a front reflector, 38% were equipped with side reflectors, and 15% were equipped with an operational headlight. Bicycles involved in nighttime accidents were no more or less likely to be equipped with proper lighting equipment than bicycles involved in daytime accidents. Only seven percent of the bicycles were equipped with a safety flag, and less than five percent were equipped with a rear-vision mirror.

Although about one-fifth of the bicycles had at least one defect at the time of the accident, few of the defects were judged contributory. The only types of defects judged contributory in more than one percent of the cases were defective brakes and a chain that was improperly adjusted. Missing or inadequate bicycle lighting equipment was judged to be contributory in about eight percent of the cases.

Most of the motor vehicles were free of defects and were properly equipped when the accident occurred. The findings of this study correspond closely with the findings of other studies which indicate that less than one percent of all bicycle/motor-vehicle accidents involve a defective motor vehicle.

Characteristics of Accident Trip

Trip purpose. About 80% of the bicyclists and 96% of the motorists were on a utilitarian trip to a specific destination when the accident occurred. Approximately equal numbers of bicyclists were traveling for the following purposes: shopping or errands (22%), commuting to place of recreation (21%), visiting friends (19%), and commuting to school or work (19%). Although only 18% of the accidents occurred while the bicyclist was on a recreational trip with no destination, household surveys have revealed that between 50% and 60% of all bicycle trips are of this type.

The most common trip purposes for motorists include: shopping or errands (41%), commuting to school or work (29%), visiting friends (14%), and commuting to a place of recreation (13%).

Trip length. Most operators were on a relatively short trip when the accident occurred. The median one-way trip length was 1.1 miles for bicyclists and 5.8 miles for motorists.

Weather conditions. Most of the accident trips were made during conditions of fair weather. A small, but significant, number of accidents occurred when rain was falling (three percent of the non-fatal cases and six percent of the fatal cases). Only a fraction of one percent of the cases occurred when it was snowing, during a period of heavy fog, or in an area with blowing sand or dust.

Lighting conditions. About 17% of all accident trips were made during darkness. However, it was found that a significantly greater proportion of fatal (30%) than non-fatal (10%) accidents occurred during darkness. These findings provide strong support for the contention that likelihood of sustaining fatal injuries from a bicycle/motor-vehicle accident is significantly greater when the accident occurs at night.

In addition to a greater likelihood of fatal injuries at night, it is probable that accident rate is also far higher at night. Although no data have been located that provide an accurate estimate of the amount of all bicycle riding that is done during darkness, casual observation and discussions with a large number of bicyclists indicate that night riding accounts for no more than three or four percent of most bicyclists' total riding time.

Characteristics of the Accident Location

Urban vs. rural accidents. A proportionate sample of urban and rural accidents was not drawn for this study. However, based upon the findings of this study and data reported elsewhere, it is estimated that about 32% of all fatal accidents and 11% of all non-fatal accidents occur in a rural area. These data leave no doubt that the likelihood of sustaining fatal injuries is greater for accidents that occur in rural areas. It is also probable that accident *rate* is higher in rural areas, but it will be necessary to obtain data on the relative amount of riding that is done in urban and rural areas in order to assess the differences in accident rate.

Land use. The proportion of non-fatal accidents that occurred in the various types of areas (predominant land use) is as follows: low-income residential (16%), middle-income residential (39%), upper-income residential (4.4%), business or commercial (22%), recreational (2.4%), and agricultural (15%).

Proximity to operator's residence. Most accidents occurred in close proximity to the operator's residence. The median distance between the accident site and the operator's residence was .6 mile for bicyclists and 2.6 miles for motorists. These findings, along with the finding that most operators had driven through the accident site many times before the accident occurred, enable one to confidently conclude that lack of familiarity with the accident site is seldom a factor in bicycle/motor-vehicle accidents.

Posted speed limit. The majority of accidents occurred on roadways with a posted speed limit of 30 MPH or less. However, the likelihood of fatal accidents was found to be positively correlated with the posted speed limit for the roadway on which the accident occurred. The distribution for non-fatal accidents showed that over 80% of the non-fatal accidents occurred on roadways with a posted speed limit of 35 MPH or less. In contrast, more than half of all fatal accidents occurred on roadways with a speed limit greater than 35 MPH; less than one-third of the fatal accidents occurred on roadways with a posted speed limit of 25 MPH or less.

Lateral and vertical curvature of roadway. It was found that one or both operator's pre-crash path was on a laterally curved roadway in only 3.6% of the cases. About seven percent of the motorists and ten percent of the bicyclists were traveling on a measurable hill at the time of the crash or shortly before. For motorists, equal numbers were traveling uphill and downhill. However, a significantly larger proportion of the bicyclists was traveling downhill than uphill. This finding undoubtedly is due to the higher speeds bicyclists travel when riding downhill, and indicates that, on the average, accident risk is greater when traveling downhill. Riding downhill at an excessive speed was judged contributory in about six percent of the cases.

Roadway-surface defects. About 12% of the accidents occurred on a roadway with one or more significant defects. However, roadway-surface defects were found to be contributory in less than three percent of the cases.

The Accident Consequences

Injury severity. It was found that the 166 fatal cases and the 753 non-fatal cases in this sample resulted in a total of 172 persons killed and 765 persons injured. All the fatalities were bicyclists except one motorist and one motor-vehicle passenger--both were riding a motorcycle. All of the injured parties were bicyclists except 25 motorists and four motor-vehicle passengers. Based upon the injury data that were compiled, a bicyclist who is involved in a bicycle/motor-vehicle accident, on the average, suffers the following consequences:

- 1.4 days in the hospital
- 1.4 days in bed at home
- 7.4 days missed work or school
- 23.6 days suffered pain or discomfort

As will be shown in the discussion of problem types, the incidence of fatal injuries is greatest for the types of accidents in which the bicyclist is sturck by a motor vehicle traveling at a sustained speed, particularly on rural roadways where the operating speed of the motor vehicle is typically above 40 MPH. Conversely, fatal injuries seldom occur when the bicyclist strikes the motor vehicle and the impact velocity is a sole function of the bicyclist's speed.

Injury type, cause, and location. An examination of the injury types revealed that 76% of the injuries were body-surface injuries, 17% were skeletal injuries, and six percent were internal, non-skeletal injuries. Over 60% of the injuries were the result of the bicyclist's impact with the roadway; 24% resulted from his impact with the motor vehicle. Only six percent resulted from the bicyclist's impact with the bicycle he was riding. The main implication of these findings is that protective clothing has far more potential for injury reduction than padding the bicycle or eliminating protrusions on the bicycle. Examination of the potential value of various types of protective clothing revealed that knee padding would affect 14% of the injuries, a helmet would affect 11% of the injuries, elbow padding would affect nine percent of the injuries, and a face guard would affect eight percent of the injuries. Six percent of the injuries would be affected by each of the following: shin padding, foot/ankle protection, gloves or mittens, and hip padding.

PROBLEM-TYPE DESCRIPTIONS

A total of 36 unique problem types were identified during this study, but it was found that a large proportion of the cases was accounted for by a relatively small number of problem types. For instance, the 25 most frequently occurring problem types accounted for 87% of the fatal cases and 93% of the non-fatal cases; 67% of the fatal cases and 64% of the non-fatal cases were accounted for by the ten most frequently occurring problem types. The following discussion is limited to seven frequently occurring problem types that together accounted for 49% of the fatal cases and 52% of the non-fatal cases.

Problem Type 1 (6.7% Fatal; 5.7% Non-Fatal)

Accidents of this type occur at the junction of an urban or rural roadway and a residential driveway or alley. Most of the bicyclists involved in this type of accident were very young: one-half were younger than ten years of age, and five percent were 5.2 years of age or younger. Ninety-five percent of the accidents occurred during the daytime. The typical case can be described as follows.

> *The bicyclist rides straight out of the driveway or alley--without slowing or stopping--and collides with a motor vehicle approaching from the left in the near lane, or from the right in the far lane. By the time the motorist observes the bicyclist and makes a correct assessment of the bicyclist's intended path, there is insufficient time to avoid the accident--even though the motor vehicle is traveling at a speed at or below the posted speed limit. The operator's view of the other vehicle may be obstructed by parked motor vehicles, vegetation, or structures located close to the junction. Whether or not a visual obstruction is present, the bicyclist fails to search in the direction of the motor vehicle until an accident is imminent.*

The motorist's failure to search in the bicyclist's direction was usually due to his assumption that vehicles entering the roadway from intersecting driveways and alleys would yield. The bicyclist's failure to slow and search for approaching traffic may be due to a variety of reasons, but the most common are faulty risk assessment and momentary distractions.

Countermeasure approaches suggested by Problem Type 1 include: the removal of visual obstructions, barriers or baffles (across driveways) that would cause bicyclists to reduce their speed before entering the roadway, devices to increase the daytime conspicuity of bicycles, education and training for bicyclists and their parents, and regulations requiring bicyclists to come to a complete stop before entering a roadway from a driveway or alley.

Problem Type 5 (7.8% Fatal; 10.1% Non-Fatal)

Problem Type 5 includes accidents that occur when a bicyclist fails to slow or stop at an intersection controlled by a stop sign. This type of accident usually occurs during the daytime (94%) at the intersection of a pair of two-lane roadways that carry only light traffic (75%). About one-half of the bicyclists involved in this type of accident were younger than 12 years of age, and more than five percent were younger than seven years of age. The following description typifies the accident cases that were classified into Problem Type 5.

> *The bicyclist approaches the signed intersection at an average or above average speed, sometimes riding on the right-hand side of the roadway, and sometimes riding on the left facing traffic. The bicyclist is aware of the stop sign controlling the roadway he is traveling, because he has ridden through the intersection many times before. The bicyclist also knows that the law requires bicycles to stop for stop signs. Nevertheless, the bicyclist enters the intersection without stopping, slowing significantly, or searching in the direction of the motor vehicle approaching the intersection on an orthogonal leg. The motorist may observe the bicyclist and infer that he will slow or stop before entering the intersection. In either case, there is insufficient time for the motorist to avoid the accident once he observes the bicyclist and recognizes that he does not intend to slow or stop. The bicycle and motor vehicle most often collide before the bicyclist reaches the center of the intersecting roadway (64%).*

The motorist's failure to search in the bicyclist's direction was usually the result of his assumption that intersecting traffic would yield to him. The bicyclist's failure to slow or stop and his failure to search for approaching traffic were most commonly due to one or more of the following: faulty risk assessment, competing needs (need to conserve time or energy), and momentary distractions. In about one-third of the cases, vegetation growing close to the intersection partially or totally obstructed the motorist's view of the bicyclist until both vehicles were close to the junction.

Countermeasure approaches suggested by Problem Type 5 include: devices to increase the daytime conspicuity of bicycles, education and training of bicyclists and their parents, and more rigid enforcement of the laws governing speed control at controlled intersections.

Problem Type 8 (5.3% Non-Fatal; No Fatal)

All of the accidents classified into Problem Type 8 occurred as the motorist was attempting to enter a roadway from a commercial driveway. About 93% of the accidents occurred during the daytime. The traffic on the roadway usually was moderately heavy or heavy at the time the accident occurred; a slight majority of the roadways had four or more traffic lanes. The age of the bicyclists involved in this type of accident varied widely. About five percent of the bicyclists were seven years of age or younger, and five percent were over 50 years of age. However, about one-half of the bicyclists were between 13 and 17 years of age.

> *In the typical case, the motorist approaches the roadway/driveway junction, brings his vehicle to a complete stop, and searches for approaching traffic in a manner that would be considered normal for motorists in this situation. When the motorist considers it safe, he enters the roadway without observing the bicyclist approaching from the left (on the roadway or sidewalk), or from the right (on the roadway or sidewalk). The bicyclist observes the motor vehicle long before reaching the junction, but proceeds through the junction because he assumes that he has been (or will be) observed by the motorist, and that the motor vehicle will remain stationary until he has passed through the junction.*

When the bicyclist was approaching from the motorist's right, riding on the sidewalk (33%) or riding in the roadway against traffic (30%), the motorist failed to search in the bicyclist's direction because he did not expect a hazard to be approaching from that direction. In the cases in which the bicyclist was approaching from the motorist's left, most motorists reported that they searched to the left one or more times, but failed to observe the approaching bicyclist even though the view was unobstructed and the visibility conditions were near optimal. Information overload, attentional conflict, and selective perception are the most probable reasons for the motorist's failure to perceive the bicyclist who clearly was within his field of view one or more times during the search process.

The general countermeasure approaches suggested by Problem Type 8 include: sidewalk-surface designs that would cause bicyclists to reduce their speeds when approaching driveway junctions, devices to increase the daytime conspicuity of bicycles, education and training for bicyclists and motorists, regulations prohibiting sidewalk riding, and increased enforcement of laws governing wrong-way riding.

Problem Type 9 (1.2% Fatal; 10.2% Non-Fatal)

Problem Type 9 includes cases in which the motorist entered an intersection from a roadway controlled by a stop sign and collided with a bicyclist who entered on an uncontrolled leg of the intersection. Accidents of this type occur in both urban and rural areas and on a variety of roadway types, but they most commonly occur at the junction of a pair of two-lane urban roadways. About 17% of the accidents occurred during darkness.

Problem Type 9 involved an older group of bicyclists than any problem type discussed previously. The median age of the bicyclists involved in this type of accident was 16.3 years, and few of the bicyclists were very young: less than five percent of the bicyclists were younger than ten years of age; slightly over one-half of the bicyclists were between 13 and 20 years of age.

The nature of the accident-generation process for Problem Type 9 is nearly the same as that described above for Problem Type 8, so the scenario of the typical case will not be repeated. However, the following characteristics of Problem Type 9 should be emphasized:

- The motorist stopped and searched for traffic, but entered the intersection without having observed the bicyclist;
- Three-fourths of the accidents occurred before the motorist reached the center of the roadway;
- About two-thirds of the bicyclists were not observed by the motorist because they were riding on the wrong side of the roadway--approaching from a direction in which motorists seldom search;

- Bicyclists riding on the correct side of the roadway at night were not observed because of darkness, inadequate front lighting, or both;
- Bicyclists riding on the correct side of the roadway were not observed because of information overload, attentional conflict, and selective perception;
- Some bicyclists failed to search in the motorist's direction, but most observed the motor vehicle well in advance and proceeded through the junction with the assumption that they had been or would be observed by the motorist.

The countermeasure approaches that are suggested from a study of Problem Type 9 include: relocating the stop line to provide the maximum buffer zone between the position of stopped vehicles and the normal path of bicyclists, devices to increase the daytime and nighttime conspicuity of bicycles (when viewed from the front), education and training of bicyclists and motorists, and increased enforcement of laws governing wrong-way riding and laws governing bicycle riding at night without proper front-lighting equipment.

Problem Type 13 (24.6% Fatal; 4.0% Non-Fatal)

Problem Type 13 must be considered one of the most important problem types revealed by this study, because it accounted for nearly one-fourth of all fatalities in the sample--three times as many as any other problem type. The distinguishing characteristics of this problem type are (a) the motor vehicle overtook and collided with a bicycle traveling in the same direction as the motor vehicle, and (b) the collisions occurred because the motorist failed to observe the bicyclist until the accident was imminent. Although accidents of this type occurred in a variety of traffic contexts, the following description typifies about 70% of the cases that were classified into Problem Type 13.

> *The collision occurs at night on a narrow, rural-type roadway. There is no ridable shoulder or sidewalk adjacent to the roadway, so the bicyclist rides along the right-hand edge of the traffic lane. The bicyclist rides farther from the edge of the roadway than he would during the daytime because he cannot see well enough to detect road-surface*

defects and debris along the extreme edge of the roadway. As the motor vehicle overtakes the bicyclist, its position in the traffic lane is slightly to the right of center and it is traveling at or near the posted speed limit--usually 45-55 MPH. Although the motorist is searching the roadway ahead, he fails to observe the bicyclist until it is too late to avoid the accident.

The motorist's failure to observe the bicyclist was a function of darkness, inadequate bicycle lighting, high closing velocity, and the expectation by motorist's that the roadway would be void of bicycle traffic at that hour. In about one-third of the cases, the influence of the above factors were compounded by the effects of alcohol consumed by the motorist a short time before the accident.

Young adult and adult bicyclists were more often involved in this type of accident than juveniles. One-half of the bicyclists in the non-fatal sample were older than 18.3 years, and one-half of the bicyclists in the fatal sample were older than 20.5 years.

Potential countermeasure approaches for Problem Type 13 include: increasing the functional width of the roadway, devices to increase the nighttime conspicuity of the bicycle (rear view), education and training of bicyclists, prohibition of night riding on selected types of roadways, establishment of more rigid standards for rear lighting of bicycles, and increased enforcement of the laws governing driving while intoxicated and the laws governing riding bicycles during darkness without lawful rear lighting.

Problem Type 18 (8.4% Fatal; 8.4% Non-Fatal)

Nearly every case classified into Problem Type 18 is accurately characterized by the following brief description.

Prior to the collision, the bicyclist is riding along the right-hand edge of the roadway, traveling in the same direction as motor-vehicle traffic in the adjacent lane. Without searching to the rear and without signaling, the bicyclist initiates a left-hand turn and collides with an overtaking motor vehicle. The overtaking motorist observes the bicyclist well in advance, but has no time for evasive action once the bicyclist begins to turn.

The actions that led to accidents of this type are clearcut and easy to describe, but the fundamental causes of the accident--the factors contributing to the bicyclist's failure to search behind and signal before turning--are not fully understood. Based upon the composite evidence now available, it appears that the bicyclist's failure to search in this situation is due to the combined effects of three factors. First, the bicyclist is always reluctant to search behind because it is difficult to do so without loss of balance and lateral control. Second, the bicyclist knows that the roadway on which he is traveling carries light and sporadic traffic. Third, the bicyclist has learned that auditory cues usually signal the presence of overtaking motor vehicles and has developed the habit of relying on auditory cues to detect overtaking motor vehicles unless traffic is heavy and continuous. It is not known for certain why the bicyclist failed to hear the overtaking motor vehicle with which he collided, but the most probable reasons are momentary distractions and ambient noise that masked the sound of the overtaking motor vehicle.

It was found that one-half of the accidents of this type occurred on a two-lane urban street and that 30% occurred on a two-lane rural roadway. Only one-half of the bicyclists initiated their turn at a point that was in close proximity to an intersecting street or driveway. Nearly all of the accidents occurred during the daytime and involved a juvenile bicyclist.

Countermeasure approaches that may prove effective in curtailing Problem Type 18 include: development of effective rear-vision devices for bicycles, widening the traffic lane to provide a greater "buffer zone" between bicyclists and overtaking motor vehicles, education and training of bicyclists, and increased enforcement of the laws governing the use of hand signals when turning. It is especially important to teach bicyclists the hazards of relying solely on auditory cues to detect overtaking motor vehicles.

Problem Type 23 (7.6% Non-Fatal; No Fatal)

Problem Type 23 includes accidents that occurred when a motorist made a left-hand turn and collided with a bicyclist approaching from the opposite direction. Accidents of this type typically occur in the daytime on an urban street with four or more traffic lanes. More adult than juvenile bicyclists were involved in this type of accident. The median age of the bicyclists was 20.1 years, and more than three-fourths of the bicyclists were 16 years of age or older. The typical case for Problem Type 23 is described below.

> *As the motorist approaches an intersection where he intends to make a left-hand turn, he slows his speed or comes to a complete stop to await a safe gap in the approaching traffic. The motorist continuously scans the one or more lanes of approaching traffic until he considers it safe to turn. At that time, he searches in the direction of the intersecting roadway and commences his turn without having observed the approaching bicyclist. The bicyclist approaches the intersection at a relatively high rate of speed. The bicyclist may fail to search in the direction of the turning motor vehicle or may observe the motor vehicle and assume it will yield to him. In either case, the bicyclist has insufficient time to avoid the accident once he observes the motor vehicle and realizes that it is going to turn into his path.*

In about one-fifth of the cases, the motorist's failure to observe the bicyclist was partly due to degraded visibility (darkness, sun glare, or glare from artificial lights). In most of the remaining cases, the motorist searched in the bicyclist's direction one or more times and failed to observe him, even though visibility conditions were near optimal. Information overload, attentional conflict, and selective perception are the most common factors that contributed to the motorist's failure to observe the bicyclist in this situation.

Countermeasure approaches suggested by the study of Problem Type 23 include: devices to increase the daytime and nighttime conspicuity of bicycles, education and training of motorists and bicyclists, and increased enforcement of the laws governing night riding without proper lighting equipment.

CONCLUSIONS AND RECOMMENDATIONS

GENERAL CONCLUSIONS

Representativeness of the Sample

The samples of fatal and non-fatal accident cases compiled during this study are considered to be reasonably representative of *police-reported* bicycle/motor-vehicle accidents that occur throughout the United States. Furthermore, the set of problem types identified during the course of this study are considered both representative and exhaustive. That is, it is concluded that (a) the problem types reported here occur with about the same frequency in most areas throughout the United States, and (b) there are few bicycle/motor-vehicle accidents that are so unique that they could not be classified into one of the 36 problem types reported here. No evidence was found that the causes of a given problem type differ in any important way from one geographical area to another. This is not to say, however, that the various contributory factors are equally common from one area to another.

Accident Causes

A major conclusion of this study is that the causes of the vast majority of bicycle/motor-vehicle accidents are behavioral. In well over 60% of the cases, the bicyclist's pre-crash course was suboptimal, indicating that a predisposing or precipitating error was made before the other vehicle could have been observed. The motorist's pre-crash course was suboptimal in about one-fifth of the cases. The implication of this finding is that countermeasures for a substantial portion of the accidents must focus on the operator's pre-crash course, rather than on his responses at the time the other vehicle first becomes observable.

When there was sufficient time to have avoided the accident once the other vehicle first could have been observed, the accident was usually precipitated by a search or evaluation failure by one or both operators. The results indicate that most of the function failures by motorists were the type that would be committed by most motorists who found themselves in a similar situation. Conversely, the function failures committed by bicyclists were most often behavioral errors in the true sense of the word. That is, the function failures represented errors that would seldom be committed by a reasonably knowledgeable and safety-conscious bicyclist. Therefore, another general conclusion drawn from the results of this study is that few motorists' function failures and most bicyclists' function failures represent aberrant behavioral errors. This general conclusion does not apply to intoxicated motorists. It can also be concluded that aberrant behavioral errors are far more common among juvenile than adult bicyclists. Except for intoxication, the operators' behavioral errors are seldom the result of a temporary or permanent impairment.

Contrary to popular beliefs, bicycle/motor-vehicle accidents are seldom the direct or indirect result of roadway-surface defects, debris on the roadway surface, sewer grates, bicycle defects or failures, motor-vehicle defects or failures, riding double, bicycle too large or too small for the operator, bicycle-handling skill deficiencies, hostile acts by motorists, high risk acceptance by bicyclists, or the bicyclist's deficient knowledge of traffic laws and ordinances. The non-behavioral factors that are the most important contributors to bicycle/motor-vehicle accidents include: visual obstructions, narrow roadways (selected locations), darkness, daytime and nighttime conspicuity of bicycles, and the vertical dimension of the bicycle/bicyclist unit.

Countermeasure Approaches

It is concluded that the countermeasure approaches listed in this report are feasible and have the potential for effecting a significant reduction in bicycle/motor-vehicle accidents. Most of the countermeasure approaches that have the greatest potential for accident reduction are listed above, at the end of the descriptions of the seven problem types. A much more comprehensive discussion of countermeasures is presented in Section V. The next task that must be accomplished is to conduct the research required to develop and evaluate specific countermeasure devices, procedures, and materials.

RECOMMENDATIONS

Programmatic Recommendations

Dissemination of information. The results of this study show that many of the current beliefs about the causes of bicycle/motor-vehicle accidents are erroneous. These erroneous beliefs currently are resulting in the expenditure of time and resources on remedial programs that have little potential for accident reduction. For this reason, it is recommended that a program be developed to disseminate information about the problem types to individuals and agencies who are involved in developing or implementing bicycle-safety programs. The groups that should be given highest priority include: educational institutions, law enforcement agencies, transportation planning organizations, parent/teacher organizations, bicycle clubs, public service organizations, bicycle manufacturers, and concerned governmental agencies at all levels.

Evaluation and refinement of countermeasure approaches. It would be unrealistic to assume that all countermeasure approaches have been identified in this report. The Office of Driver and Pedestrian Research, National Highway Traffic Safety Administration, presently has a program underway which will enable a multi-disciplinary team of experts to study the problem types in detail, evaluate the countermeasure approaches suggested in this report, attempt to identify other innovative countermeasure approaches, and formulate recommendations about specific countermeasures that should be developed and evaluated. It is recommended that local and state agencies and special-interest groups be encouraged to engage in a similar activity but focus on the problems and constraints present within a specific state, county, or community. In addition to the identification of unique and innovative countermeasures, such an activity would have great educational value for those involved.

Implementation of selective enforcement programs. It is recommended that communities throughout the country be urged to develop and implement a selective enforcement program which focuses on critical violations by specific bicyclist target groups. The critical violations include:

entering the roadway from a driveway or alley without slowing, stopping, or searching for traffic (local ordinances will be required to make this action unlawful); riding on the wrong side of the roadway; failure to stop for stop signs; entering a signalized intersection during an amber signal phase (additional regulations may be required); and turning without signaling or searching for traffic. The target population for the selective enforcement program is mainly juveniles. A more specific description of the target population for each of the critical violations is presented in Section V.

Requirements for Additional Research

Bicyclist behavior. There are at least three germane questions about accident causation that were not fully answered by this study. One of the most critical questions concerns the role of hazard recognition and risk assessment in juveniles' selection of a non-optimal course, and their failure to search in critical situations. Research is needed to (a) identify the features in the environment that represent obvious cues to hazard for adult bicyclists, but either are not perceived or are not correctly evaluated by juveniles; and (b) identify the environmental features that juvenile bicyclists consider when assessing the risk associated with a specific behavioral act at a specific location.

A second important question that remains unanswered concerns the reasons why juvenile bicyclists fail to search to the rear before initiating a left-hand turn. Research is needed to (a) evaluate bicyclists' capability to maintain control of their bicycles when scanning to the rear, (b) determine the extent to which this specific skill can be enhanced through training, (c) determine the extent to which bicyclists rely on auditory cues to detect overtaking motor vehicles, and (d) identify the traffic contexts in which bicyclists tend to rely on auditory cues.

A third question concerns the manner in which a bicyclist's behavior changes when riding with a companion--particularly when the bicyclist is following his riding companion. Many bicyclists reported that their selection of a suboptimal course and their failure to search for hazards was due to their assumption that the lead bicyclist would perform these tasks. It is likely that this behavior pattern is more common than was reported by the bicyclists. Research is needed to (a) determine the manner in which a bicyclist's behavior changes when he is trailing another bicyclist, and (b) assess the absolute frequency with which this "blind following" behavior contributes to accident-producing actions by the trailing bicyclist.

Bicycle modifications. Developmental research is required to (a) create devices that will increase the vertical dimensions of the bicycle, and thereby increase the likelihood that it will be observed when partly obscured by parked motor vehicles and other low-lying objects; (b) create devices to increase both the daytime and nighttime conspicuity of bicycles; and (c) create rear-vision devices for bicyclists that are effective, safe, and acceptable to the bicycle-user population.

Education and training. It is anticipated that a considerable amount of research will be required to define the most cost-effective methods for imparting the requisite knowledge and skills to the various parties who would benefit from education and training. Research on the education and training of bicyclists and motorists should receive the highest priority.

Regulations and enforcement. Research is required to assess the feasibility of selective prohibitions, including: (a) prohibiting bicycle riding on specific types of roadways; (b) prohibiting riding during specific times of the day or night (general, or at specific locations); (c) prohibiting riding by bicyclists younger than a specified age; and (d) prohibiting riding until bicyclists are able to demonstrate specific knowledge and skills. Research is also required to identify effective deterrents for the critical violations.

SECTION II
INTRODUCTION

This section commences with a description of the project objectives and a discussion of the magnitude of the bicycle/motor-vehicle accident problem; the remainder of the section is devoted to a discussion of the rationale underlying the methodological approach adopted for this study.

PROJECT OBJECTIVES

Stated in the broadest sense, the objectives of this project were to compile data on the causes of bicycle/motor-vehicle accidents and to use these data to identify countermeasure approaches that have the potential for reducing the number of accidents of this kind. The project was national in scope and encompassed both urban and rural accidents. The *specific* objectives of this project were as follows.

- Identify the frequently occurring problem types[1] that occur in the United States.
- Estimate the relative frequency with which the various problem types occur.
- Determine if the problem types that occur in urban areas are different than those occurring in rural areas; for problem types common to both areas, determine whether the relative frequency of occurrence is the same in urban and rural areas.
- Determine if there are problem types that result in a disproportionate number of fatal injuries.
- Identify and evaluate potential countermeasures for each problem type (to the extent possible without undertaking countermeasures test and evaluation research).

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[1]As will be discussed in more detail later, the term "problem type" refers to a group of accidents that are caused by a similar combination of factors and events. In principle, accidents of the same type should be amenable to the same specific countermeasures, so a problem type represents a well-defined problem for which specific countermeasures can be tailored.

- Formulate recommendations about further research that is required to define the problem types in a more definitive manner, or to better assess potential countermeasure approaches.

MAGNITUDE OF THE PROBLEM

The National Safety Council reports that bicycle/motor-vehicle accidents have resulted in about 1,000 fatalities and about 40,000 disabling injuries[2] each year since 1972 (National Safety Council, 1976). Although the National Safety Council's data are the best available gauge of the magnitude of the problem, their estimates are conservative because they are based only on police-reported accidents. Recent survey data indicate that a substantial number of the bicycle/motor-vehicle accidents that occur each year are *not* reported to the police. For instance:

- A survey of 1,307 motorists in Santa Barbara County revealed that 4.2% of the motorists had been involved in a bicycle/motor-vehicle accident in the recent past, and that only 25% of the accidents were reported to the police (Cross & deMille, 1973).
- In a nationwide survey of 23,699 elementary school children, students were required to describe their most serious accident during the past year, or if none their most serious accident during the past five years. Of the 393 students who indicated that their most serious accident was a bicycle/motor-vehicle accident, only 37% indicated that their accident was reported to the police (Chlapecka et al., 1975).
- In the present study, the bicyclists and motorists who were interviewed were asked if they had been involved in any bicycle/motor-vehicle accidents during the past 24 months *other* than the one being investigated. It was found that the combined samples had been involved in a total of 47 bicycle/motor-vehicle accidents and that only 27% of the accidents were reported to the police.
- Although not directly relevant for the United States, it is interesting to note that a recent survey study showed that only 25% of the injury-producing bicycle/motor-vehicle accidents in Birmingham, England, were reported to the police (Bull & Rogerts, 1973).

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[2]The National Safety Council defines a disabling injury as one causing death, permanent disability, or any degree of temporary total disability. Temporary total disability is defined as an injury which renders the injured person unable to perform regular duties on one or more full calendar days after the day of the injury.

One explanation for these findings is that many bicycle/motor-vehicle accidents result in little or no injury, and that it is these inconsequential accidents that are not being reported to the police. Although little is known about the consequences of unreported bicycle/motor-vehicle accidents, some information on this issue was obtained from the data compiled by Chlapecka and his colleagues (1975). At the request of the authors of this report, a special analysis of Chlapecka's data was performed to determine the consequences of the unreported bicycle/motor-vehicle accidents in the sample. The results showed that more than 50% of the unreported accidents were severe enough to require some form of medical treatment (Schupak, 1975). Unfortunately, the data were not in a form that enabled a more precise assessment to be made of the degree of injury sustained in the unreported accidents.

Although data on the incidence of bicycle/motor-vehicle accidents are meager, it is nevertheless possible to define the general bounds of the problem. Since the National Safety Council's estimates are based on police-reported accidents, it seems reasonable to assume that these estimates--1,000 fatalities and 40,000 disabling injuries--represent the lower limit of the problem. But what about the upper bounds? First, consider the number of fatalities that occur each year. Because nearly all fatal accidents are reported to the police, the National Safety Council's estimate of 1,000 fatalities per year should be quite accurate. This view is reinforced by the fact that the National Safety Council's estimate of fatalities corresponds closely with estimates of the National Highway Traffic Safety Administration, who publishes a monthly running total of fatal accidents--including bicycle/motor-vehicle accidents.

Next, consider non-fatal but injury-producing accidents. If the survey data cited above are assumed to be representative of the nation, it can be estimated that about one-third of all bicycle/motor-vehicle accidents are reported to the police, and that about one-half of the unreported accidents are injury producing. Using 40,000 as the estimated number of police-reported accidents, it can be estimated that a total of about 80,000 injury-producing bicycle/motor-vehicle accidents occur each year.

Another source of information about the magnitude of the bicycle/motor-vehicle accident problem is the data compiled through the National Electronic Injury Surveillance System (NEISS). This system was developed by the Consumer Product Safety Commission to compile data on product-related injuries that are treated in the emergency rooms of a selected sample of 119 hospitals throughout the United States. The NEISS records do not include injuries treated in a doctor's office or at home, so the data are not comprehensive enough to provide an accurate estimate of the absolute number of injury-producing accidents.[3] However, the NEISS data provide useful information about the severity of bicycle/motor-vehicle accidents relative to other bicycle-related accidents. The NEISS data for calendar year 1975 show that 82% of all bicycle-related fatalities and 5.5% of all bicycle-related injuries are the result of a bicycle/motor-vehicle accident (Rowe, 1977). These statistics--82% of fatalities and 5.5% of injuries--are doubly impressive in view of the fact that bicycle/motor-vehicle accidents account for only a fraction of one percent of all bicycle-related accidents. These data leave little doubt that bicycle/motor-vehicle accidents account for a disproportionate number of the consequential bicycle-related accidents.

UNDERLYING RATIONALE

The research methodology described in Section III is an outgrowth of a variety of considerations about the nature of the accident-generation process, the best way to study this process, and ways by which the process can be altered to effect a reduction in the incidence and consequences of accidents. The considerations that have had the most significant impact on the methodological approach used in this study are described below.

[3]A national household survey, conducted in 1970, showed that only 38% of all disabling product-related injuries are treated in an emergency room (Food and Drug Administration, 1972).

CONCEPT OF ACCIDENT CAUSATION

The research approach adopted for this project centers on the identification of factors that are causally related to the accident or, stated differently, the pattern of a combination of factors that together caused the accident to happen. Because of the key role of accident causation in this project, it is necessary to define the meaning of the term as it is used throughout this report.

Purpose of Defining Cause

The cause of a traffic accident can legitimately be defined in a variety of ways, depending upon one's purpose. Probably the most common purpose of defining accident cause is to establish legal liability for an accident. When an accident victim or witness is asked to define accident cause, he will typically respond by describing the particular set of pre-crash actions and conditions that he considers relevant for the assignment of legal liability. Therefore, the term cause is most often used to connote fault, culpability, or liability.

The traffic-safety specialist's purpose of defining accident causation is to define what can be done, within his particular specialty area, to reduce the incidence and the consequences of traffic accidents. Vehicle-design specialists define causation in terms of vehicle attributes that are causally related to accidents; educational specialists define accident causation in terms of the operator's knowledge and skill deficiencies that are causally related to accidents; and highway designers and traffic engineers define accident causation in terms of the attributes of the static and dynamic environment that are causally related to traffic accidents. Each of these definitions of accident cause is perfectly legitimate and utilitarian. The definitions serve to focus the specialist's attention on the factor or factors *he* can change to effect a reduction in the likelihood that a similar accident will recur. Most specialists are fully aware that accidents are usually the result of a *combination* of interrelated factors, but explain that it would be impractical for them to spend time defining accident cause in terms of factors that fall outside their area of expertise and control.

The purpose of identifying cause in this project is similar to that of the traffic-safety specialist's, but somewhat broader in scope. The causes of bicycle/motor-vehicle accidents are identified because it is assumed that the knowledge will lead to insights about what can be done to eliminate this kind of accident. However, since the purpose of the project was to identify the full range of countermeasure approaches, accident cause is defined in terms of the full range of factors that may contribute directly or indirectly to a bicycle/motor-vehicle accident, including:

- *OPERATOR FACTORS*--Operator factors include operator conditions that were subnormal or atypical at the time of the accident and that contributed directly or indirectly to the accident. Operator factors also include specific behavioral acts performed by the operator that are considered subnormal or atypical and that had a contributory effect.
- *VEHICLE FACTORS*--Vehicle factors include vehicle failures and vehicle design features that contributed directly or indirectly to the accident.
- *ENVIRONMENTAL FACTORS*--Environmental factors include weather conditions, lighting conditions, roadway conditions, traffic conditions, and any other environmental object or condition that contributed to the accident.

Assumption of Multiple Causation

A causal factor is defined as a condition or event that is necessary for an accident to occur, but it is assumed that there is no single causal factor that is sufficient in itself to produce an accident. Examination of the circumstances surrounding a specific accident may lead an investigator to conclude that the accident would not have occurred if the operator had not been intoxicated, the street surface had not been covered with ice, the vehicle's braking system had not been worn, or it had not been snowing. Although it may be true that the accident would not have occurred if any one or more of these factors had been absent, their presence is not sufficient to produce an accident in every case. The same is true of accident-producing events. It is not possible to define an event that will produce an accident under all circumstances. Even a catastrophic failure of the operator or vehicle does not always lead to an accident. It follows that accident cause must be defined in terms of some combination of factors that *together* are both necessary and sufficient to produce an accident.

Sequential and Simultaneous Factors

The authors concur in principle with the traditional view that an accident is the end product of a chain of events, and that the cause of the accident must therefore be defined in terms of a set of events that are sequentially related to one another. But it may be misleading to imply that the accident-generation process is closely analogous to a *chain*. Such an analogy suggests--at least implicitly--that each event in the "chain" has one and only one antecedent. In reality, an event is usually, if not always, the result of multiple, simultaneously occurring antecedents--each being necessary, but not in itself sufficient, to cause the event in question to occur. According to this conceptualization, the terminal event (accident) has a set of simultaneously occurring antecedents; each antecedent of the terminal event, in turn, has its own set of simultaneously occurring antecedents; and so on. Thus, a fully comprehensive definition of accident causation would require a listing of both the sequential and the simultaneous antecedents and a description of how the antecedents are related to one another.

If one accepts the premise that every event has a cause, it follows that the chains of antecedents could be traced backward in time from the accident to the operator's birth, or before. So the question becomes, how far back in time should one attempt to trace the chains of antecedents? For this project, cause is defined in terms of the events that occurred and the conditions present during the "trip"; that is, the period between the accident and the point in time when the operator commenced his pre-trip preparations. It is assumed that knowledge of the events that occur and the conditions present during this time period will, in most cases, provide a clear picture of what must be changed to effect a reduction in accidents.

MODEL OF ACCIDENT-GENERATION PROCESS

Many researchers have recognized the need to formulate a conceptual model of the accident-generation process to help structure their thinking about specific data requirements and methods for data analysis and interpretation. The authors of this report experienced a similar need for structure in the study of bicycle/motor-vehicle accidents. The model developed to fulfill this need is illustrated in Figure 1 and described below.

The conceptualization of the accident-generation process described here has been influenced greatly by the work of Snyder et al. (1971) and, to a significant but lesser extent, by the work of Baker (1961), Baker and Ross (1961), Fell (1974), McGlade and Laws (1962), and Perchonok (1975).

Terminal Event

The terminal event is an accident involving a bicycle and any type of motor vehicle, or a collision with another vehicle or object that resulted from an attempt to avoid a bicycle/motor-vehicle collision. Information about the terminal event alone provides no insight about accident causation, but is needed to assess the consequences of the accident and the potential value of "at-crash" countermeasures.

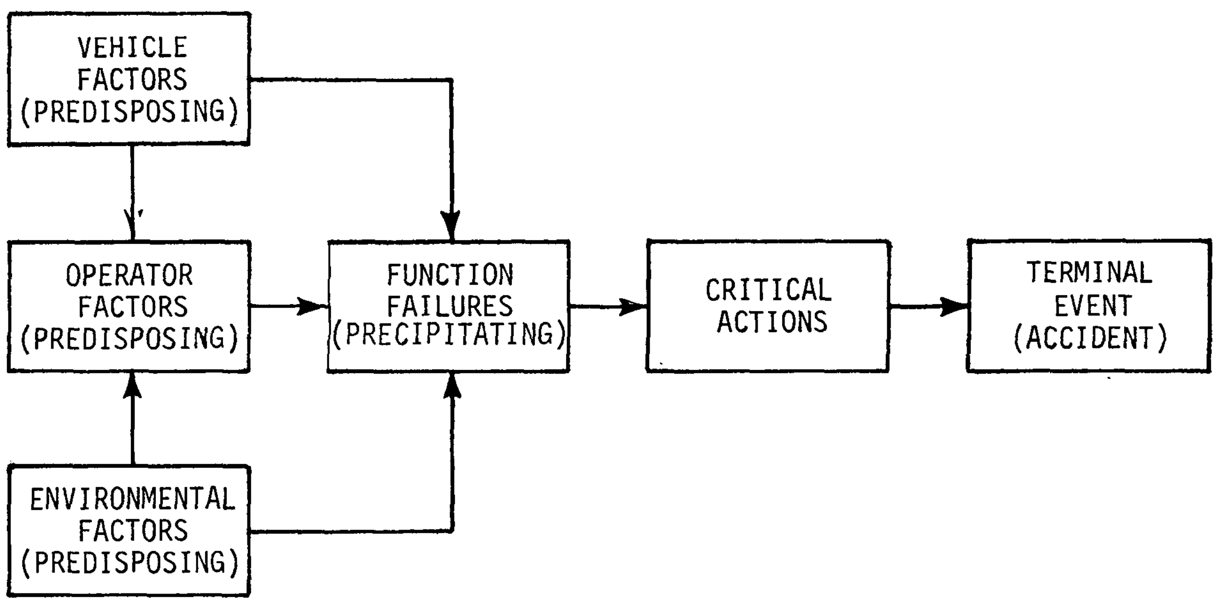

Figure 1. Conceptual model of the accident-generation process.

Critical Actions

Critical actions refer to the vehicles' actions and movement patterns that led directly to the accident. Using the concepts developed above, critical actions are the events that are the immediate antecedents of the crash. The critical actions constitute the ultimate target for accident countermeasures, and the only criterion for the success of a countermeasure is whether it produces the desired change in the critical actions of at least one of the vehicles.

Critical actions cannot *meaningfully* be described out of context. Little understanding is gained by knowing only that an accident occurred when a vehicle was turning left, turning right, proceeding straight ahead, accelerating, decelerating, and so on. These are commonplace actions and movement patterns that are performed every day. Contextual data are needed to understand why the actions proved critical on that particular occasion. Therefore, a meaningful definition of the critical actions must include a description of the relevant attributes of the roadway and traffic environment in which the critical actions occurred.

Function Failures

The critical actions serve to define what must ultimately be changed in order to effect a reduction in accidents, but knowledge of the critical actions alone provides no insight about how to achieve the desired change. Such insight can be gained only by examining the chains of events that preceded the critical actions. Events that are causally related to the critical actions can be characterized as *operational failures* of the traffic system. That is, one or more elements of the traffic system failed to perform as expected. Operators can fail, vehicles can fail, and certain elements of the environment can fail.

Operator failures. An operator failure must be defined in terms of the operational rules--formal and informal--that have evolved for the traffic system. An operator failure may be the result of the operator's failure to perform an expected function; or conversely, it may be the result of an operator's performance of a function that is unexpected. Clearly, the capabilities and limitations of vehicle operators in general must be considered in assessing whether or not a failure occurred. It cannot be said that an operator failed because he was incapable of reacting instantaneously, because he was incapable of processing a vast quantity of information, or because he failed to perform other superhuman feats. When such is the case, one must look elsewhere for the failure. When considering operator failures, a question arises as to whether subnormal physical conditions, mental conditions, knowledge, or skill should be considered to be operator failures. It is believed that it is best to define operator failures only in terms of behavioral acts that should not have been performed or acts that should have been performed but were not. Operator characteristics or conditions that influence behavior will be defined as predisposing factors.

Vehicle failures. A vehicle failure occurs when the vehicle fails to perform within the range of normalcy. The inability to stop would be classified as a vehicle failure if the braking system performed in a subnormal manner for that particular type of vehicle. Obviously, the inability of a vehicle to literally "stop on a dime" could not be considered a failure.

Vehicles may be designed in a way that makes them incapable of performing within the range of normalcy under some circumstances. Although it could be said that faulty design constitutes a vehicle failure, it is usually more meaningful to define the function failure in terms of a more proximal event, and to identify faulty design as a predisposing factor.

Environmental failures. In the true sense of the word, there are few elements in the environment that can fail. There is no question that malfunctioning traffic signals, flashing warning lights, street lights, and railroad-crossing barricades should be considered environmental failures. But, what about substandard roadway surfaces, poorly placed signals, nonstandard roadway designs, inclement weather, and the many other environmental elements that may be causally related to accidents? As was true with faulty vehicle design, it is believed that it is preferable to define the failure in terms of a more proximal event, and to identify environmental elements as predisposing factors.

Causal Factors

Causal factors are the operator factors, vehicle factors, and environmental factors that are causally related to the function failure. As depicted in Figure 1, vehicle and environmental factors may lead directly to a function failure, or the effect may be mediated by the operator. Whether the effect of vehicle and environmental factors is direct or indirect has important implications for countermeasures development. If the effects of factors are mediated by the operator, there are two countermeasure options. One can either eliminate or modify the factor directly, or one can enhance the operator's ability to cope with it.

In principle, the contributory effect of most, if not all, vehicle and environmental factors is mediated by the operator. Loose gravel may contribute to a function failure, but only because of the operator's failure to recognize and cope with it. Narrow roads or heavy traffic may be contributing factors, but only because of the operator's inability and/or disinclination to counter these factors by modifying his course or selecting a safer route. Similarly, an operator can behave in a manner that would offset the effects of faulty brakes, poor vehicle design, darkness, visual obstructions, and a host of other vehicle and environmental factors. In practice, whether an effect should be considered direct or indirect depends on the ease with which a normative operator could be expected to develop the knowledge and skill required to counteract the effect.

BEHAVIORAL SEQUENCE MODEL

The evidence available at the outset of this project indicated that most bicycle/motor-vehicle accidents are precipitated by an operator failure. Since it was expected that a very large proportion of the function failures for bicycle/motor-vehicle accidents would be behavioral, it was considered important that a conceptual framework be developed that would prove useful in identifying and defining the behavioral acts that constitute function failures.

The Behavioral Sequence Model, developed by Snyder et al. (1971) for the study of pedestrian accidents, appeared to have equal utility for the study of bicycle/motor-vehicle accidents; so Snyder's model was adopted for this study along with most of his terminology. The events that occur prior to the time vehicles enter on a collision course appear to have somewhat more relevance for bicycle/motor-vehicle accidents than for pedestrian accidents. So the model described here places somewhat greater emphasis than did Snyder on the events that occur prior to the selection of a collision course. Also, as is discussed below, specific anchor points in the accident-generation process have been defined that are not a part of Snyder's model.

The Behavioral Sequence Model used here encompasses the events and actions that occur during the trip the operator was taking at the time the accident occurred. The trip has been subdivided into three functional phases: the Preparatory Phase, the Anticipatory Phase, and the Reactive Phase. Each of the three phases are defined below, along with a discussion of the functions of interest during each phase.

Preparatory Phase

The Preparatory Phase commences when the operator makes a decision to execute a trip and terminates at the point at which the operator begins the task of selecting a course through the accident area. The functions that must be performed during the Preparatory Phase are of two types, "evaluation" and "decision." An operator must evaluate his own capability and that of his vehicle to execute (or continue) the desired trip under the environmental conditions that will be (are) encountered during the trip. The operator must also evaluate alternate routes to his destination in terms of his momentary trip objectives.

An *evaluation failure* occurs when an operator fails to recognize the operator, vehicular, and environmental factors that affect the likelihood that his trip will be completed safely, or when the operator fails to assess correctly the degree to which such variables affect accident likelihood. An evaluation failure also occurs when an operator draws incorrect inferences about the relative safety of alternate routes, or when the operator fails to recognize that meeting a time schedule he has set for himself will require him to operate his vehicle at unsafe speeds.

A *decision failure* occurs when the operator performs the necessary evaluations correctly, but decides to execute or continue a trip with the full recognition that his condition, his vehicle's condition, or the environmental conditions make it unsafe to do so. Also, decision failures occur when the operator bases his route selection and scheduling decisions on considerations other than safety.

It is unlikely that events occurring during the Preparatory Phase will lead to failures from which it is not humanly possible to recover, so failures during the Preparatory Phase will ordinarily be predisposing rather than precipitating. Exceptions to this rule are the cases in which the operator's performance capability is impaired to such an extent that he is clearly incapable of executing the trip safely. For instance, when the operator's performance is impaired seriously by alcohol or drugs, or when the operator is suffering from a serious physical or sensory impairment, the precipitating failure *could* be attributed to evaluation or decision failures during the Preparatory Phase.

Anticipatory Phase

The Anticipatory Phase commences at the point where the operator begins to perform the tasks required to select a course through the accident area. This phase terminates at the point where the other vehicle (the vehicle with which the operator subsequently collided) first could have been observed if the operator had been looking in the proper direction. This point in time and space is termed "the point first observable." There are six sequential functions that must be performed in order to select an appropriate course through an area. These functions are defined below. Keep in mind that these functions are performed prior to the point at which the other vehicle could have first been observed. Also, keep in mind that the purpose of these functions is to select and implement a course through the accident area, rather than to evade a specific conflict.

- *SEARCH*--The operator must search the portions of the environment that contain information relevant for course selection. As the term is used here, the search function includes both the scanning and the perceptual process. The search function is not performed effectively unless the operator searches for and consciously perceives *all* the relevant elements *that are visible*. Although it would be useful to identify cases in which the operator scanned in the direction of an object but did not perceive it, such a determination is nearly impossible with post-accident interview data.

- *DETECTION*--The operator must detect the elements in the traffic environment that are relevant for course selection. As the term is used here, a detection failure occurs only when the operator's sensory capabilities (vision and/or auditory) are temporarily or permanently impaired, when the relevant elements are obscured from view by an obstruction, or when the visibility conditions are seriously degraded (poor lighting conditions, atmospheric attenuation, etc.). This represents a deviation from other, and probably more common, definitions of the detection function.

- *EVALUATION*--The operator must integrate the information that he has perceived; he must identify alternate courses through the area; he must estimate the relative safety of each alternative course; and he must correctly identify the course that *objectively* is most safe. An evaluation failure occurs when an operator concludes that the objectively safest course is no more safe or less safe than other courses available to him.

- *DECISION*--The operator must decide upon a course that best fulfills his momentary needs. When an operator has strong momentary needs that are in direct competition with the need for safety, he may perform a trade-off decision in a perfectly rational way and conclude that a suboptimal course (any course other than the safest one) better suits his needs. Such a conclusion represents a decision failure, even if the operator's conclusion was logical--given the relative strength of the competing needs. In short, a decision failure occurs whenever an operator selects a course that he knows is less safe than available alternatives.

- *OPERATOR ACTION*--The operator must perform the perceptual-motor tasks required to guide his vehicle through the selected course. An inability to accomplish these tasks represents an operator-action failure.

- *VEHICLE ACTION*--The vehicle must respond in a normal way to the operator's control inputs. A vehicle-action failure occurs when the vehicle fails to respond or responds in an abnormal way.

The operator's course is defined in terms of the vehicle's path and speed; so a course may be suboptimal because an operator selected a suboptimal path, or because he was traveling at a suboptimal speed, or both. When the operator's course is suboptimal, a predisposing or precipitating failure can be traced to one of the Anticipatory-Phase functions. Whether the failure is precipitating or predisposing depends upon the time available to perform the Reactive-Phase functions once the other vehicle first becomes observable. The function failure is precipitating if the suboptimal course creates a situation in which successful evasive action is not humanly possible once the other vehicle first becomes observable. The function failure is predisposing if the suboptimal course makes evasive action more difficult but not impossible.

Reactive Phase

The Reactive Phase commences at the point where the other vehicle first becomes observable, and terminates at the collision point. The Reactive-Phase functions are defined below, and a model is presented that depicts the characteristics of the function/event sequence for the Reactive Phase. Also described are the special anchor points that have been defined for the Reactive Phase of the accident-generation model.

Reactive-Phase functions. The critical functions that must be performed during the Reactive Phase are of the same general type as those that must be performed during the Anticipatory Phase, but differ in terms of their objective. The objective during the Anticipatory Phase is course selection, while the objective during the Reactive Phase is collision avoidance. The differences are reflected in the function definitions listed below.

- *SEARCH*--The operator must search the relevant portions of the environment for potentially threatening vehicles. As was true for the Anticipatory Phase, the search function includes both the scanning and the perceptual processes. Therefore, a search failure occurs when the other vehicle is visible but not consciously perceived by the operator.

- *DETECTION*--The operator must detect the presence of vehicles that constitute a potential hazard. Again, a detection failure occurs only when the operator cannot detect the other vehicle because of temporary or permanent sensory impairments, visual obstructions, or degraded visibility conditions.

- *EVALUATION*--The operator must assess the velocity vector of the other vehicle with respect to his own, and must judge whether or not his vehicle is on a collision course with the other vehicle. If the operator judges that the vehicles *are* on a collision course, he must identify alternative evasive actions and evaluate their probable effectiveness in reducing accident likelihood. If the vehicles are *not* on a collision course, the operator must judge whether a collision course could be introduced by a change in the direction or velocity of the other vehicle; he must assess the likelihood that such an event will occur; and he must identify and assess alternative courses of action. An evaluation failure occurs when an operator fails to recognize the need for evasive action and identify the evasive action that minimizes accident likelihood or, if a collision is imminent, the force of the impact.

- *DECISION*--The operator must choose the evasive action that best suits his momentary needs. A correct decision is made only when the operator chooses the evasive action that he perceives to be most safe.

- *OPERATOR ACTION*--The operator must perform the motor behavior that is required to implement the evasive action he decided upon.

- *VEHICLE ACTION*--The vehicle must respond to the operator's motor inputs in a normal manner.

If a precipitating failure does not occur during the Preparatory or Anticipatory Phase, a precipitating failure *must* occur at some point during the Reactive Phase.

Function/event sequence for Reactive Phase. Figure 2 shows the sequence of Reactive-Phase functions and possible outcomes for the bicyclist and motorist. This diagram, with only minor modifications, was taken from Snyder's report on pedestrian accidents (Snyder, et al., 1971, p. 3-3)

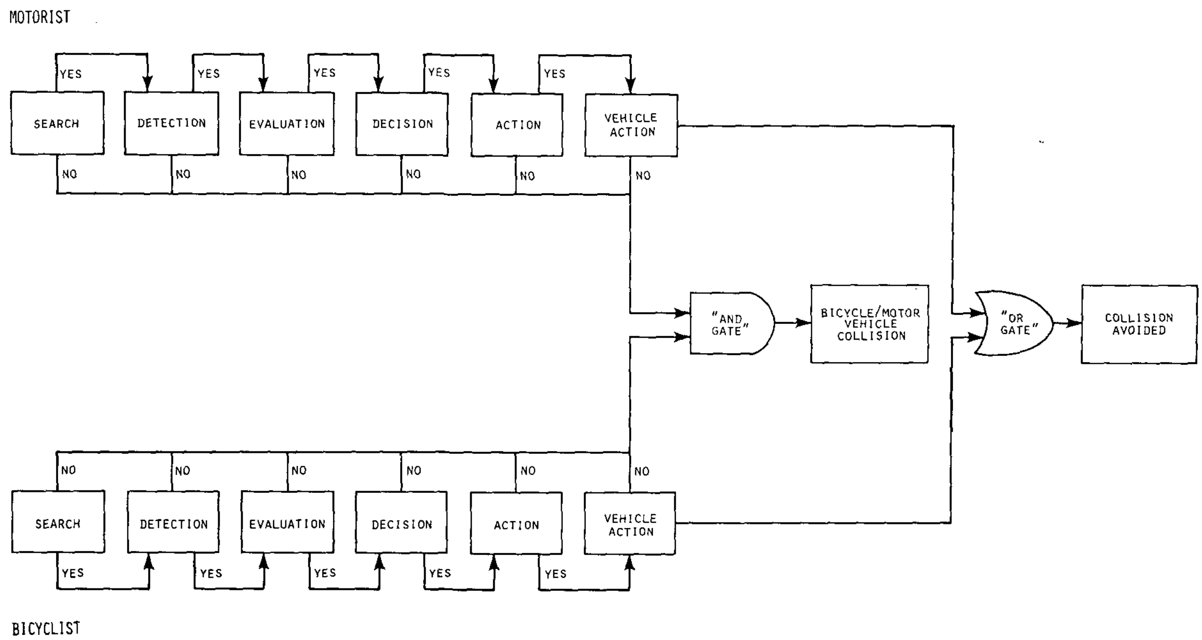

Figure 2. Generalized function/event sequence.

because it vividly illustrates two important characteristics of the Reactive Phase. First, failure to perform one function adequately precludes the possibility of adequately performing the following functions. If an operator fails to search in the direction of the other vehicle, he cannot detect it; if the operator does not detect the other vehicle, he cannot perform the evaluation function; and so on. Second, it can be seen that an accident is avoided if *either* the bicyclist or motorist performs all the functions adequately; or, stated differently, an accident occurs only if *both* the bicyclist and the motorist fail to perform one of their functions adequately. It follows that a complete definition of the cause of an accident must identify a function failure for *both* the motorist and the bicyclist.

Some readers might find it difficult to accept the notion that a totally non-culpable operator has "failed." This difficulty stems from a tendency to confuse function failures with fault or culpability. Although it is true that many function failures are the direct result of an operator error, this is by no means always true. There are many instances in which a totally innocent operator cannot perform a function because it is simply not humanly possible to do so. Detection failures occur, but the operator cannot be faulted for being unable to see through a block wall. Evaluation failures occur, but the operator cannot be faulted for being unable to anticipate a completely atypical maneuver by the other operator.

Identifying the function failure of the non-culpable operator is necessary to fully describe the accident-generation process; moreover it can be of great value in defining ways the non-culpable driver's behavior can be modified to effect a reduction in accident likelihood. Indeed, defensive driving schools assume that collisions can be avoided by *either* party, and they concentrate on enhancing the knowledge and skills that enable a normally safe and lawful driver to counteract the mistakes of drivers who lack the inclination or ability to drive safely.

A function/event flow diagram similar to the one shown in Figure 2 could be prepared for both the Preparatory- and Anticipatory-Phase functions.

Anchor points within the Reactive Phase. Locating a function failure is a relatively simple matter when an operator simply fails to perform a function altogether. It is more difficult to locate the function failure when the function is performed with a sufficient degree of accuracy or precision, but an inordinate amount of time is consumed in doing so. In order to identify a failure of this type, one must have evidence that the amount of time consumed in performing the function is substantially greater than would be required by a "normally" alert and capable operator (hereafter referred to as a "normative" operator).

An after-the-fact assessment of the amount of time that an operator spent in performing a specific function is difficult. It is equally difficult to judge reliably the amount of time a normative operator would require to perform the same function under the same set of circumstances. Yet it is these types of judgments that are required to identify where in the behavioral sequence the function failure occurred.

In order to assess the timeliness with which the functions are performed, it is necessary to determine where in time and space the functions were performed. As an aid in defining the information required to assess the timeliness of operator functions, five key anchor points along the accident vehicle's path were defined. These anchor points are described below.

- *COLLISION POINT*--The point at which the vehicles collided; or, if the vehicles did not collide, the point of the first harmful event.
- *POINT OF FIRST EVASIVE ACTION*--The point at which the operator first initiated action in an attempt to avoid a collision; or, if a collision was imminent, to reduce the force of impact.
- *POINT OF FIRST ALARM*--The point at which the operator first recognized that his vehicle was on a collision course with another vehicle, and that a collision would occur if evasive action was not taken by one or both operators.
- *POINT OF FIRST DETECTION*--The point at which the presence of the other vehicle was first perceived.
- *POINT FIRST OBSERVABLE*--The point at which the presence of the other vehicle could first have been detected if the operator had been scanning in the proper direction and had been alert.

Knowledge of the location of the above anchor points and knowledge of the vehicles' speeds at these points enables one to make estimates of the amount of time that was available to perform the functions and the amount of time used to perform each function. Figure 3 and the following discussion illustrates, in principle, the types of conclusions that can be drawn from a knowledge of the location of the anchor points.

The circles in Figure 3 depict the location of the anchor points along a hypothetical time dimension--time before crash. Thus, in this example, the Point First Observable was located 44 time-units before the crash; the Point of First Detection was located 31 time-units before the crash; and so on. Since the Reactive Phase does not commence until the other vehicle first becomes observable, the time interval t_1 is the total amount of time available to perform all of the Reactive-Phase

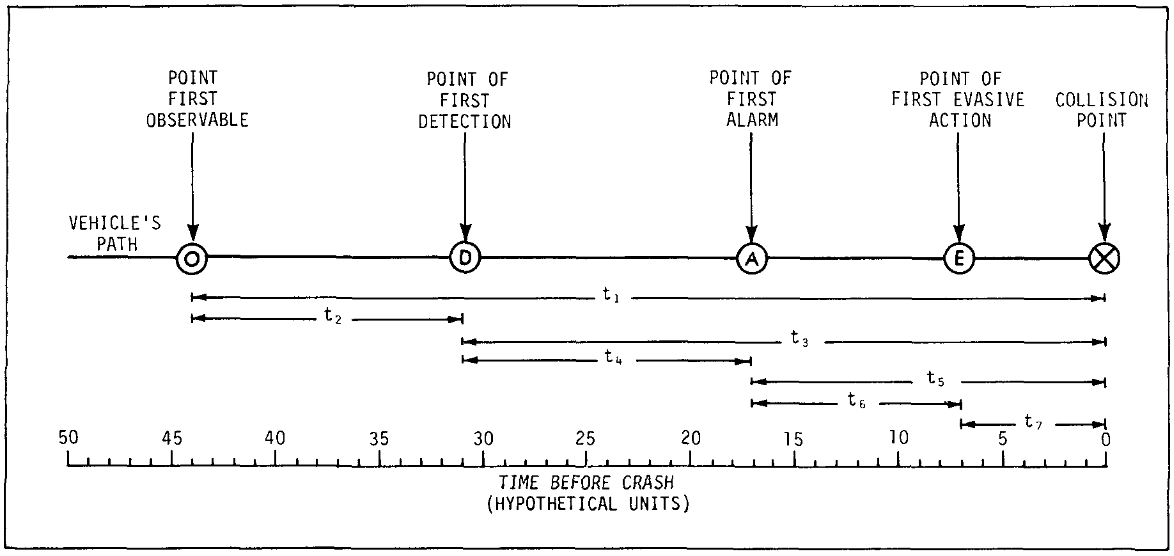

Figure 3. Illustration of use of anchor points in assessing time available and time used to perform behavioral-sequence functions.

functions. If a normative operator would require more time than t_1 to perform the Reactive-Phase functions, it cannot be said that a function failure occurred during the Reactive Phase. The time interval t_2 shows the amount of time actually used to perform the search and detect functions. Time interval t_3 is the time available to perform the remaining functions in the behavioral sequence (evaluation, decision, operator action, and vehicle action).

For purposes of illustration, assume that t_1 *is* time enough for a normative operator to perform all the Reactive-Phase functions; and further assume that t_3 is *not* enough time for a normative operator to perform the remaining functions (evaluation, decision, and action). It follows that an excessive amount of time was consumed in performing the search and detection functions. The location of the function failure is therefore narrowed to one of two functions, search or detection. Additional information would be required to determine which of the two functions was performed inadequately.

By definition, the Point of First Alarm is the point at which the operator completes the evaluation function; so the time interval t_4 is the amount of time that was used in performing the evaluation function. The time interval t_5 is the amount of time available to perform the decision and action functions. If t_3 is adequate time for a normative operator to perform the remaining functions but t_5 is not, it can be assumed that the operator used an excessive amount of time to perform the evaluation function.

Time t_6 is the amount of time used to perform the decision and operator-action functions. If it is assumed that operator response time is a constant (k), then the time taken to perform the decision function equals t_6-k. Time t_7 is the amount of time available to perform the vehicle-action function. When crashes occur, t_7 is always an inadequate amount of time to complete the vehicle action, regardless of which function it was that failed.

The utility of the anchor points in assessing the timeliness of functions is limited by the accuracy with which anchor points can be located in space, speed can be estimated, and normative performance can be predicted. As will be discussed later, the interview procedure and other aids were designed to maximize the accuracy of these determinations. Even under the best of circumstances, however, the assessment is subject to error of estimation.

NEED FOR ACCIDENT CLASSIFICATION SCHEME

The methodological approach adopted for this study centers on the development of an accident classification scheme for use in classifying individual accident cases into a set of mutually exclusive problem types. Since accident classification plays such a key role in this project, it seems worthwhile to comment briefly on why this approach was selected over other, more conventional, approaches.

Like other types of traffic accidents, bicycle/motor-vehicle accidents exhibit great diversity in the situations in which they occur and the reasons for which they occur. When every case is viewed as a unique event, the universe of bicycle/motor-vehicle accidents presents an overwhelmingly complex picture to even the most capable researcher. The nature of the problem, and therefore approaches to reducing the problem, simply cannot be comprehended without structuring the universe of accidents in some meaningful way. Therefore, the primary requirement for an accident classification scheme stems from the need to structure a complex universe of accident cases in a manner that facilitates an understanding of the fundamental characteristics of the cases, individually and collectively.

Probably the most common method for structuring a complex universe of objects or events is to develop a classification scheme that enables one to subdivide the universe of cases into mutually exclusive "sets" by grouping together objects or events that exhibit commonality in one or more of their attributes. Classification schemes have been developed and used since the days of the early Greeks (Crowson, 1970), and much of the progress in the physical and biological sciences can be attributed to this tool for scientific inquiry (Sokal, 1974). More recently, classification schemes have been developed and successfully used in the study of pedestrian accidents (Snyder, et al., 1971) and alcohol-related motor-vehicle accidents (Perchonok, 1975).

The ultimate value of an accident classification scheme depends largely on the criteria used for classification. Although it is possible to classify accidents in terms of any arbitrarily chosen descriptive variable (vehicle type, roadway type, operator's age, and so on), one has no assurance that the accidents classified into the same set are any more similar with respect to the accident-generation process than a group of accidents selected at random. If one's purpose of investigating accidents is to understand the nature of the accident-generation process, the candidates for classification criteria are limited to variables that are causally related to the accident. Therefore, the development of a truly useful accident classification scheme would require the accomplishment of the following tasks.

- Investigate each accident case in detail.
- For each case, identify the variables (failures and factors) that are causally related to the accident-generation process.
- Group together accident cases that exhibit commonality in one or more of the variables shown to be causally related to the accident.

A second factor that has an important influence on the utility of a classification scheme is the degree of commonality that must be exhibited by accident cases in order to qualify them for classification into the same type. There are no fixed rules for defining the degree of commonality that is best. A requirement for commonality in virtually every attribute undoubtedly would result in a vast number of problem types, each with only a few cases. Even though highly specific countermeasures could be defined for each type, so few cases would be affected by a given countermeasure that its cost could seldom be justified. Conversely, a requirement for commonality in only a small number of attributes would result in problem types that are so general that they would have little utility for identifying countermeasures that are specific enough to be effective.

Thus, decisions about the optimal degree of commonality must be based on a consideration of the specificity with which countermeasures can be defined, the probable number and consequences of accidents that would be affected, and the cost of implementing the countermeasure. This study was designed to provide the information required to make such decisions. More will be said later about how the accident classification scheme was developed and the procedure used to classify accident cases into specific categories that are referred to here as "problem types."

SECTION III
METHODOLOGY

This section describes the methods and procedures that were used to compile and analyze data on bicycle/motor-vehicle accidents. A brief overview of the methodological approach is followed by a more detailed description of the specific methods and procedures that were employed. For the sake of brevity, lengthy descriptions of procedures, specimens of data-collection instruments, and coding indexes are presented in the appendices. Volume 2 of this report contains a copy of the *Field Investigator's Instruction Manual* (Appendix A), specimens of the questionnaires and other data-collection instruments (Appendix B), a detailed description of the post-interview evaluation procedure (Appendix C), and supporting data not included in Volume 1 (Appendix D). Volume 3 contains the coding index for the questionnaires (Appendix E) and the post-interview evaluations (Appendices F and G).

OVERVIEW

Data on bicycle/motor-vehicle accidents were collected in four sampling areas in the United States. The sampling areas were selected to provide maximum coverage of the characteristics of the bicycling population and the environmental conditions in which they ride. The sampling areas, each consisting of several contiguous counties, were located in California (Los Angeles area), Colorado (Denver/Boulder areas), Florida (Tampa/Orlando areas), and Michigan (Detroit/Flint areas). A proportionate sample of accident cases was selected from those occurring during each month of calendar year 1975, and an attempt was made to select equal numbers of urban and rural accidents at each sampling area. A case was rejected from the sample if it was an unwitnessed hit-run accident or if both of the involved operators refused to be interviewed.

Data on each accident case in the sample were compiled by a trained Field Investigator. Following a highly structured data-collection procedure, the Field Investigator compiled and recorded data from several sources, including: the official traffic accident report, observations and measurements taken at the accident location, and detailed interviews with the vehicle operators and persons who witnessed the accident. A structured questionnaire and a detailed scale drawing of the accident site were used to conduct the operator interviews.

Some questionnaire items were designed to provide information about the characteristics of the operator, his vehicle, and his trip. However, most items were designed to provide detailed information about the accident-generation process. The interview procedures and instruments were designed to provide a clear notion of the pre-crash path of both vehicles, the function failure of each operator, and the combination of factors that were causally related to the function failures.

After the data forms were cleaned and verified by home-office personnel, the Principal Investigator studied the data for each case and made the final judgment about the function failure for each operator and the factors that contributed to the function failures. The data were then encoded, punched onto IBM cards, and entered into a computerized data file.

A classification procedure was developed and the sample of accident cases was classified into mutually exclusive "types" by the Principal Investigator. Cases classified into the same type exhibited commonality in one or more of the following attributes: the traffic context in which the accident occurred, the operators' function failures, and the combination of factors causally related to the function failures. The data were analyzed as required to describe the characteristics of the sample (pooled and by problem type) and to address the issues posed in the description of the Project Objectives (see Section II).

The final task was to identify potential countermeasure approaches for each problem type and to formulate recommendations about additional research requirements.

SAMPLING PROCEDURES

SAMPLING AREAS

A sampling area was selected in each of four geographical regions[4] within the United States. Together, the four geographical regions covered a wide range of climatic conditions, topographic characteristics, and demographic characteristics. Each sampling area contained at least one large metropolitan area, and encompassed rural areas that varied in land use from purely residential (housing tracts in the urban fringe) to purely agricultural. Table 1 identifies the counties located within each sampling area and shows the size and density of the population residing in each county within the central city area, outside the central city area, and in the total sampling area.

SELECTION OF SPECIFIC CASES FOR STUDY

A quota of 200 accident cases--100 urban and 100 rural accidents--was established for each sampling area. The method used to select the sample of non-fatal cases is described below. Because of the low incidence of fatal accidents, the sample included *all* fatal accidents that occurred in the four sampling areas. In addition, a traffic accident report was obtained for each fatal accident that occurred during calendar year 1975 in in the entire States of California, Colorado, and Florida.

Definition of Monthly Quota

One objective of the sampling procedure was to select a proportionate sample of cases that occurred during each month of calendar year 1975. Since the data for 1975 were not available at the time the study was initiated, the proportion of the annual total occurring during each month of the previous year was used to define the monthly sampling quota. For instance, if it was found that six percent of the yearly total occurred

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[4]A fifth sampling area was selected in the vicinity of Baltimore, Maryland, but difficulty in locating reliable Field Investigators prevented the investigation of a significant number of cases at this location.

TABLE 1

POPULATION SIZE AND DENSITY OF SAMPLING AREAS

SAMPLING AREAS		POPULATION SIZE[1] AND DENSITY[2]							
STATE	COUNTIES	BY COUNTY		WITHIN CENTRAL CITY		OUTSIDE CENTRAL CITY		TOTAL AREA	
		TOTAL	DENSITY	TOTAL	DENSITY	TOTAL	DENSITY	TOTAL	DENSITY
MICHIGAN	WAYNE	2,267	3,747	1,874	10,136	2,834	557	4,708	893
	OAKLAND	907	1,046						
	MACOMB	625	1,302						
	GENESEE	444	691						
	WASHTENAW	234	329						
	ST. CLAIR	120	163						
	LIVINGSTON	59	103						
	LAPEER	52	79						
FLORIDA	PINELLAS	522	1,970	801	4,215	1,197	165	1,998	268
	HILLSBOROUGH	490	472						
	ORANGE	344	378						
	BREVARD	230	227						
	POLK	227	122						
	SEMINOLE	84	275						
	PASCO	76	102						
	OSCEOLA	25	19						
COLORADO	DENVER	515	5,421	575	7,602	713	198	1,228	335
	JEFFERSON	233	298						
	ADAMS	186	150						
	ARAPAHOE	162	203						
	BOULDER	132	176						
CALIFORNIA	LOS ANGELES	7,032	1,728	3,610	6,564	4,941	153	8,551	257
	SAN BERNARDINO	684	34						
	RIVERSIDE	459	64						
	VENTURA	376	202						

[1] Population totals in units of 1,000.
[2] Population density in persons per square mile.

during the month of April in 1974, six percent of the sampling quota (6% x 200 = 12 cases) was selected randomly from the pool of accidents that occurred during April of 1975.

Preliminary Selection of Cases

Arrangements were made with the accident record-keeping agency of each state to provide a monthly listing of the bicycle/motor-vehicle accidents that occurred during each month of calendar year 1975. The monthly listings were provided as soon as the accident data for the month in question had been entered in the state's data files. (Typically, there was a two to four-month lag between the time the accident occurred and the time the monthly listings could be produced.) The listing contained the accident report number and a designation of the type of area (urban or rural, as officially designated) in which the accident occurred.

The accident cases required to meet the monthly quota were selected at random from the monthly listings. The number of cases selected for each month was 50% greater than that needed to fill the monthly quota. The additional cases were selected to replace those that were rejected during the initial screening or were lost because the operators' refused to be interviewed or could not be located. An attempt was made to select equal numbers of urban and rural accidents. In some sampling areas, however, the incidence of rural accidents was so low that it was impossible to fill one-half the monthly quota with rural accidents. In these cases, every rural accident was selected, and the remaining cases required to fill the monthly quota were selected from the urban accidents that occurred during the same month.

Screening of Cases

Traffic accident reports for the cases selected were obtained and examined by home-office personnel. Hit-run accidents were rejected unless the official accident report contained the name of at least one person who witnessed the accident. In addition, a few cases were rejected because the information on the official accident report was illegible. The reports for the remaining cases were sent to the appropriate Field Investigator. At the same time, a letter was sent from the home office to each operator. The letter explained the purpose of the project and informed the operators that they would soon be contacted by a Field Investigator who would attempt to schedule a time for a home interview.

Upon receipt of the traffic accident reports, the Field Investigator attempted to contact the involved operators to arrange a time for an interview. If only one operator could be located or if only one operator agreed to the interview, an attempt was then made to solicit the cooperation of persons who witnessed the accident. Accident cases were rejected from further consideration unless at least one victim and one witness agreed to be interviewed. When a case was rejected, a replacement was drawn from the monthly pool and a "rejection form" was completed for the rejected case.

DATA-COLLECTION METHODS AND PROCEDURES

Data collection was accomplished by Field Investigators who were permanent residents of the sampling areas. All Field Investigators had prior experience in conducting home interviews and were given extensive training on the methods, procedures, and materials developed for this project. The sequence of data-collection tasks performed by the Field Investigators is described briefly below. A more detailed description of the data-collection methods and procedures is contained in the *Field Investigator's Instruction Manual* (Appendix A). Specimens of the questionnaire instruments and other materials used for data collection are contained in Appendix B.

PRELIMINARY STUDY AND PREPARATION

The tasks described under this heading were accomplished for each accident case prior to the time the first interview for that accident was conducted.

Study of Official Accident Reports

The Field Investigator's first task was to carefully study the information contained on the official accident report. This study provided the Field Investigator with a general understanding of the circumstances surrounding the accident and knowledge of the characteristics of the involved motorist and bicyclist. Although the accident reports contained limited and sometimes erroneous information, they usually provided sufficient information to enable the Field Investigator to perform the on-site inspection (described below) in an effective manner. Additionally, data recorded on the accident report were used to complete the first two pages of the *Descriptive Data Form* (Appendix B). (All the information taken from the official accident report was subsequently verified during the operator and witness interviews.) The data items obtained from the official accident report and coded onto the *Descriptive Data Form* include the following.

- Personal data on accident victims and witnesses
  - name
  - address
  - phone
  - age
  - sex
  - marital status
- Accident location
  - state
  - municipality
  - county
  - location of collision point (relative to intersection, mile post, landmark)
- Time of accident
  - date
  - month
  - year
  - day of week
  - hour of day
- Conditions at time of accident
  - weather
  - lighting
  - roadway surface
  - roadway repair
- Citations issued
- Violations not cited

- Investigating officer's assessment of:
  - bicyclist's physical condition
  - motorist's physical condition
  - vehicle condition
  - primary cause and associated factors
  - type and extent of injuries
- Disposition of injured

On-Site Inspection

At the outset of the project, the Field Investigators were required to conduct the on-site inspections on the same day of the week and same hour of the day that the accident occurred. This requirement was subsequently relaxed for two reasons. First, the requirement resulted in severe scheduling problems because many accidents occurred at the same time of day when the involved parties wished to schedule the interview. Second, because it was necessary to conduct the on-site inspection several months after the accident occurred, it was reasoned that the information about the dynamic traffic environment (traffic speed and volume, for instance) was of questionable validity even though it *was* obtained on the same day of the week and hour of the day that the accident occurred.

The tasks performed during the on-site inspection are summarized below and described in detail in Appendix A.

Photograph accident site. At least two photographs were taken of the accident site, one from the motorist's point of regard and one from the bicyclist's point of regard. The photographs were taken along the vehicles' pre-crash paths at a point 125 feet from the collision point. Other photographs were taken as required to depict the relevant features of the accident location.

Draw scale diagram of accident site. Preliminary testing revealed that accident victims experienced great difficulty in describing accurately the circumstances surrounding the accident and the location at which key events occurred. This difficulty stemmed principally from a lack of ability to make absolute distance judgments. Young operators and many adult operators apparently have not developed the ability to assess distances in terms of standard units of measurement. It was found that distance judgments are more accurately made in terms of the dimensions of common physical objects, such as car lengths, city blocks, bicycle lengths, and so on. But, it was found that the most accurate judgments about the location of events were made by describing the location of a point relative to two or more physical landmarks, such as driveways, traffic signs, houses, trees, telephone poles, and so on.

In an attempt to obtain more detailed and accurate information about the accident, informal experiments were conducted with various types of visual aids that would help the interviewee describe his pre-crash actions and the location of key events along his pre-crash course. It was found that the best technique--short of conducting the interview at the accident site--was to center the discussion around a detailed plan-view diagram of the accident site that was drawn to exact scale. For this reason, the Field Investigators were required to prepare a detailed scale-drawing of the site of each accident.

The diagram was drawn on the reverse side of the *Descriptive Data Form* (see Appendix B) at a scale of one inch equals 20 feet. The *Descriptive Data Form* was printed onto a single sheet 22" wide and 17" high, so an area 340 by 440 feet was depicted on the diagram.[5]

The Field Investigator made measurements as required to portray all relevant environmental features to scale and in their proper relative position. The diagram included roadways, sidewalks, driveways, roadway markings, regulatory signs, directional signs, traffic signals, and other roadside furniture. In addition, the Field Investigators were instructed to depict other roadside features that they believed may have influenced the operator's behavior at some point along the pre-crash path, and the features that could serve as landmarks in locating the point at which critical pre-crash events occurred. They were instructed to be particularly alert to objects

[5]For ease in binding, the specimen of the *Descriptive Data Form* shown in Appendix B has been cut in four sections. Thus, the grid side of the form on which the accident diagram was drawn appears on four separate pages.

that may have obstructed the operator's vision and objects that could have acted as a distractor for one or both operators. The coding symbols used in drawing the accident diagram are shown in Appendix B.

Encode roadway data. After the accident diagram was completed, the Field Investigator encoded the characteristics of the roadway (or roadways) the vehicles were traveling just prior to the collision. The specific data items recorded are shown in Item 12 of the *Descriptive Data Form* (Appendix B).

Assess land use in accident area. To obtain a more accurate description of the characteristics of the area in which the accident occurred, the Field Investigator was required to estimate the proportion of the "general area" (area within one-half mile radius of the collision point) and the "proximal area" (area within 300 feet radius of the collision point) that was allocated to the land-use categories listed below.

- Low-income residential
  - single-family
  - multi-family
- Medium-income residential
  - single-family
  - multi-family
- Upper-income residential
  - single-family
  - multi-family
- Business/commercial (retail stores and service establishments open to the public)
- Industrial (manufacturing and service establishments not generally open to the public)
- Recreation (parks and other non-business recreational areas)
- School (public or private educational institutions)
- Agriculture/other open (vacant lots/acreages not specifically developed for public use or residential areas where housing plots are one acre or more)

Measure operating speed and traffic volume. The Field Investigator measured operating speed and traffic volume for the roadways the operators were traveling prior to the accident. The method used to measure operating speed and traffic volume is described in the *Field Investigator's Instruction Manual* (Appendix A), and the forms that were used are shown in Appendix B.

OPERATOR AND WITNESS INTERVIEWS

The operator interviews are clearly the heart of this study because the operator has far greater knowledge about the accident-generation process than even the most observant and objective witness. An alert witness may be able to describe the pre-crash course of both vehicles, and may be able to provide a reasonably accurate account of the operators' actions prior to the crash. But, except in rare cases, only the operator is capable of providing a comprehensive description of his actions and thoughts prior to the crash and thereby provide insight about *why* he behaved the way he did. Using the concepts developed in Section II, a witness may be able to describe the critical actions and the function failures of the operators, but only the operators themselves are capable of identifying the predisposing factors that contributed to the function failures.

Despite the obvious importance of the operator interviews, it was not possible to limit the sample to cases in which both parties were available and willing to grant an interview. Limiting the sample to accident cases in which an interview with both operators was possible would have eliminated all fatal accident cases from consideration and would probably have produced a biased sample of serious-injury accidents as well. That is, since refusal rate was almost certain to be positively related to the seriousness of the accident, it appeared probable that the chances of completing a successful interview with *both* victims would be considerably less for serious-injury accident cases. (This prediction was verified by the results of this study.) Thus, although the Field Investigators made every attempt to interview both the motorist and the bicyclist, there were many cases in which only one of the operators could be located and interviewed.

Ordinarily, witness interviews were conducted when only one of the operators could be interviewed. These interviews were conducted in an attempt to supply information about the actions of the missing operator. In a few instances, witness interviews were conducted in an attempt to resolve conflicting testimony by the motorist and the bicyclist.

The following paragraphs describe the procedures and instruments used in interviewing the bicyclists, motorists, and witnesses. This description is highly abbreviated. Readers who are interested in gaining a more detailed understanding of the procedures and instruments should review the *Field Investigator's Instruction Manual* (Appendix A) and the specimens of questionnaires and other materials shown in Appendix B.

Time and Place of Interviews

The time required to complete an operator interview varied from 90 to 150 minutes; the witness interviews were usually completed in 30 minutes or less. The interviews were conducted from two to six months after the date of the accident. In about 90% of the cases, the interviews were conducted within four months of the date of the accident.

The operator interviews were ordinarily conducted in the operator's home, although a few operators preferred to be interviewed at their place of employment. One or both parents were sometimes present during interviews with very young bicyclists. Otherwise, the Field Investigator requested that only the operator be present during the interview.

Bicyclist Interviews

Background data items. The questionnaire was designed so that the least threatening questions were asked during the initial part of the interview. Accordingly, the first four pages of the *Bicyclist Interview Form* (Appendix B, page 72) contain a number of general background items that do not deal specifically with the operator's behavior at the time of the accident. For the most part, these are straightforward, highly structured questions that can be answered quickly and easily by the operator. The information that was obtained from the background data items is outlined below. The coding categories used to encode the response to each item are shown in Appendix E (Volume 3).

- Pre-crash riding experience
- Bicycle usage
- Formalized training in motor-vehicle operation

- Formalized training in bicycle operation
- Familiarity with accident vehicle (bicycle)
- Trip characteristics and route selection
- Familiarity with accident site
- Characteristics of bicycle
- Bicyclist's body dimensions
- Operator's judgment about contribution of vehicle defects and missing equipment
- Traffic citations received during past 24 months
- Prior involvement in bicycle/motor-vehicle accidents (past 24 months)
- Prior exposure to bicycle laws and ordinances
- Vehicle operator's license
- Impairments at time of accident
- Physical condition at time of accident
- Injuries (four most serious)
- Consequences of injury

Detailed discussion of the accident. The remainder of the interview was devoted to a detailed discussion of the accident. The purpose of this discussion was to obtain information needed to identify the function failures that precipitated the accident and to define the factors and events that were causally related to the function failure.

Field Investigators were trained to follow a highly structured step-by-step interview procedure that was designed to reconstruct the accident-generation process in a systematic and unobtrusive fashion. The procedure was designed to define the pre-crash path of both vehicles and the location--along the vehicles' pre-crash paths--of five key anchor points: collision point, point of first evasive action, point of first alarm, point of first detection, and point first observable. The vehicles' pre-crash paths and the anchor points were drawn onto the accident diagrams as the operators defined their locations. Having defined the locations of the anchor points, the operators were questioned systematically about the conditions that prevailed and the events that occurred during the intervals between the anchor points.

An abbreviated description of the procedural "steps" is presented below. The specific questions and data items are shown on the *Bicyclist Interview Form* (Appendix B). A detailed description of the interview procedure is presented in Appendix A; Appendix B contains specimens of the various checklists and rating instruments used during the interview.

- Explain diagram and symbols.
- Identify changes in site characteristics and modify diagram.
- Explain purpose of accident diagram and associated discussion.
- Determine if bicyclist was riding alone when the accident occurred.
- Define collision point.
- Obtain bicyclist's estimate of speed (both vehicles) at collision point.
- Define attitude of vehicles on impact.
- Define point of impact (both vehicles).
- Obtain bicyclist's assessment of type and extent of damage to bicycle.
- Define post-crash position of vehicles and bicyclist, and the path traveled between the collision point and the at-rest position.
- Draw exact path of both vehicles from edge of diagram to collision point.
- Define point of first alarm.
- Define type and location of other vehicles, pedestrians, and animals in the vicinity at the point of first alarm.
- Obtain bicyclist's estimate of speed (both vehicles) at point of first alarm.
- Define stimuli that generated first alarm, and bicyclist's conclusions about accident likelihood and requirement for evasive action (at point of first alarm).
- Define point of first evasive action by bicyclist, and identify specific action taken.
- Obtain bicyclist's estimate of speed (both vehicles) at point of first evasive action (by bicyclist).
- Obtain bicyclist's assessment of effectiveness of his first evasive action.
- Identify subsequent evasive actions by bicyclist, and obtain bicyclist's assessment of the effectiveness of each action identified.
- Define point of first evasive action by motorist, and identify specific action taken.
- Obtain bicyclist's assessment of effectiveness of motorist's first evasive action.
- Identify subsequent evasive actions by motorist, and obtain bicyclist's assessment of the effectiveness of each action.
- Define point of first detection.
- Obtain bicyclist's estimate of speed (both vehicles) at the point of first detection.
- Define reason(s) why bicyclist first detected the presence of the motor vehicle.
- Define point of assumed/actual first detection by motorist, and explain reason(s) for invalid assumption (if any).
- Identify type and location of object(s) obstructing vision (between point of first detection and point of first alarm).
- Define visibility of motor vehicle between point of first detection and point of first alarm.

- Define direction and object(s) of scan between point of first detection and point of first alarm.
- Define non-visual distractor(s) present between point of first detection and point of first alarm.
- Identify point along path where bicyclist first observed (but did not recognize) cues to hazard, and identify cues observed.
- Identify point where motor vehicle could have first been observed by the bicyclist (point first observable).
- Obtain bicyclist's estimate of speed (own vehicle) at point where other vehicle first observable.
- Identify type and location of object(s) obstructing vision (between point first observable and point of first detection).
- Define visibility of motor vehicle between point first observable and point of first detection.
- Define direction and object(s) of scan between point motor vehicle first observable and point of first detection.
- Define non-visual distractor(s) present between point first observable and point of first detection.
- Define type and location of object(s) obstructing vision prior to point first observable.
- Define visibility of accident area prior to point first observable.
- Define direction and object(s) of scan prior to point first observable.
- Define non-visual distractor(s) present prior to point first observable.
- Evaluate bicyclist's intended course through the accident area, and identify reason(s) for (suboptimal) course selection.
- Obtain rating of bicyclist's perception of riskiness of composite traffic situation.
- Request bicyclist to define the situational factors he considered in rating risk perception.
- Obtain rating of bicyclist's willingness to take risks in traffic.
- Obtain bicyclist's assessment of the factors that caused or contributed to the accident.
- Define signal state for accidents that occurred at signalized intersections.

Motorist Interview

The procedures and instruments developed for the motorist interview were nearly identical to those developed for the bicyclist interview. With only four exceptions, every item appearing on the *Bicyclist Interview Form* has a parallel item on the *Motorist Interview Form*. Items 5, 6, 8, and 15 on the *Bicyclist Interview Form* were not relevant for the motorist interview.

The procedural steps and data items used in reconstructing the accident-generation process were exactly the same for the bicyclist and motorist interview. Moreover, corresponding forms of checklists and rating instruments were used for the motorist interview. Specimens of the checklists and rating instruments are contained in Appendix B.

Witness Interview

Since the purpose of the witness interviews was to supply missing information or to resolve conflicting testimony, it was not possible to develop a highly structured interview procedure that would be applicable to all accident cases. The *Witness Interview Form* (Appendix B, page 94) contains a set of questions that were always asked during the witness interview, but most of the germane information came from an unstructured discussion directed toward resolving specific uncertainties about an accident case. Witness interviews were conducted by telephone when it was possible to do so. When witnesses could not be contacted by phone or when the issues were too complex to resolve in a telephone conversation, the Field Investigator conducted face-to-face interviews at the witnesses' homes.

FIELD INVESTIGATOR'S ASSESSMENT OF ACCIDENT CAUSATION

After completing the interviews, the Field Investigator reviewed the composite data compiled for an accident case and identified the factors judged to be causally related to the accident. On a special form provided for this purpose (see Appendix B, page 132), the Field Investigator wrote a short description of the contributing behavior of the motorist and the bicyclist and, if relevant, described operator interactions that contributed to the accident. The Field Investigator also wrote a description of any vehicular or environmental factors that were judged to be causally related to the accident.

DATA PROCESSING AND ANALYSIS

Described below are the tasks that were performed once the investigation of a case was completed and the data package sent to the home office.

DATA VERIFICATION AND ENCODEMENT

Immediately upon their arrival at the home office, the data packages were cleaned and verified by the Principal Investigator and his staff. A data analyst made a thorough check of each data package to ensure that all data forms had been completed, that the data had been properly coded, and that all coding symbols were clearly legible. Response categories were developed for items not coded by the Field Investigator and the response codes were entered on the data forms. The Principal Investigator checked each data package for complete information and for internal consistency. The data were then punched onto IBM cards, verified, and entered into a computerized data file.

POST-INTERVIEW EVALUATION

The main purpose of the post-interview evaluation was to make a final judgment about the function failures of each vehicle-operator unit and the factors that were causally related to the function failures. Additional tasks performed during the post-interview evaluation included: an assessment of the culpability of each operator, development of a coded description of the traffic context and the proximal behavior of each operator, and an assessment of whether the accident area was urban or rural in character.

The post-interview evaluation for every case was performed by the Principal Investigator in accordance with a highly structured set of rules and guidelines. A detailed description of the post-interview evaluation procedures, rules, and guidelines is presented in Volume 2 (Appendix C).

ACCIDENT CLASSIFICATION PROCEDURE

The ultimate objective of the accident classification procedure was to classify the sample of accident cases into mutually exclusive problem types. The classification procedure that was employed is illustrated schematically in Figure 4 and is described below. The "feedback loops" shown in Figure 4 illustrate that the classification tasks were performed in an iterative manner. That is, insights gained from performing the later tasks often led to a modification of the classification categories defined during an earlier task.

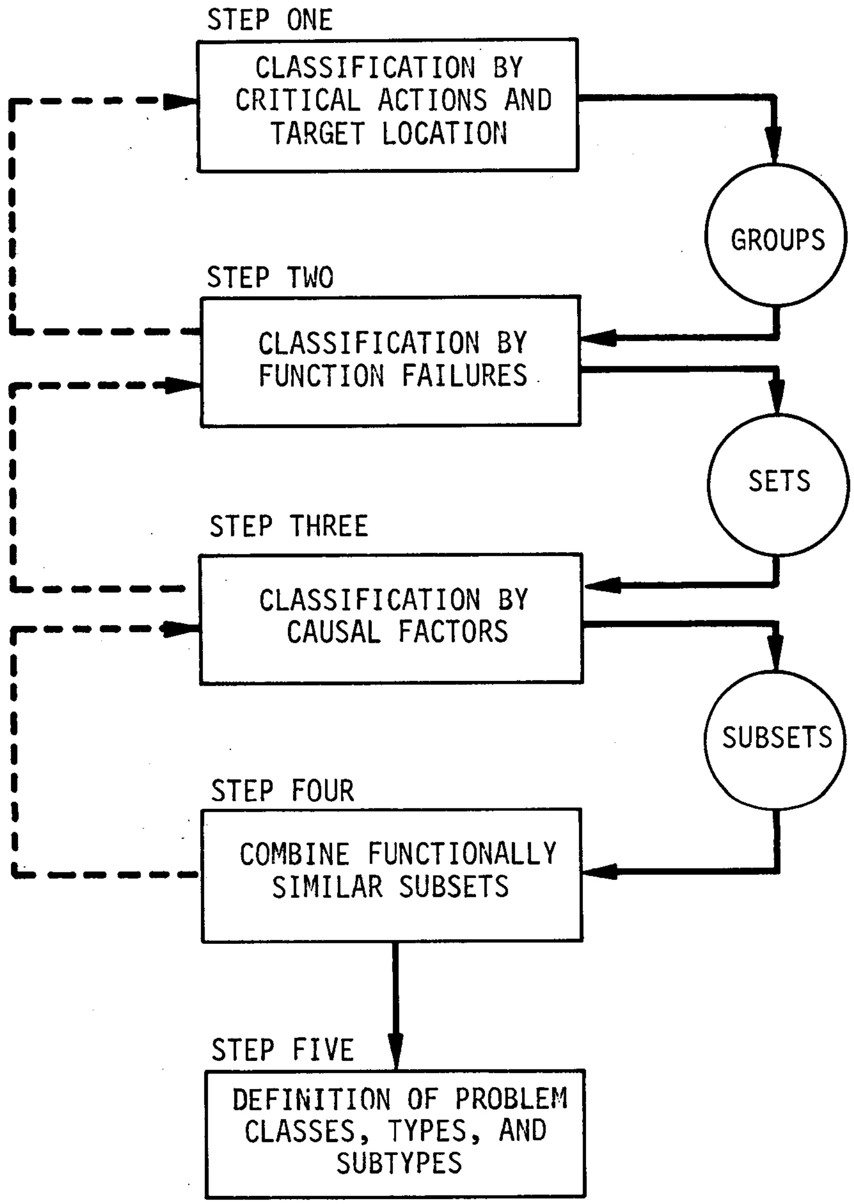

Figure 4. Task-flow diagram of accident classification procedure.

Before discussing the classification procedure, the main classification variables will be reviewed briefly. A more detailed discussion of these variables was presented earlier (see Section II).

- *CRITICAL ACTIONS*--The vehicles' actions and movement patterns that lead directly to an accident.
- *TRAFFIC CONTEXT*--The physical and operational environment in which the accident occurs. The traffic context defines the "target location" for a problem type.
- *FUNCTION FAILURES*--The functions, as defined by the Behavioral Sequence Model, that are performed inadequately or not at all.
- *CAUSAL FACTORS*--The operator factors, vehicle factors, and environmental factors that are causally related to function failures. As the term is used here, causal factors are predisposing rather than precipitating.
- *OPERATOR CHARACTERISTICS*--The attributes of human operators that have important implications for countermeasures development and implementation. A distinct target group exists when it is found that the characteristics of the operators involved in a given type of accident are more homogeneous than the characteristics of the accident population as a whole.

Classification by Traffic Context and Critical Actions

The first task was to subdivide the total sample of cases into mutually exclusive *groups* such that cases within the same group were similar with respect to the traffic context in which the accident occurred and the critical actions that led directly to the crash. Traffic context and critical actions were selected as the initial classification variables because it was observed that accidents which are similar with respect to both the traffic context and the critical actions also tend to be similar with respect to the other classification variables (function failures, causal factors, and operator characteristics).

It is important to emphasize that the use of traffic context and critical actions as the initial classification variables does *not* mean that these variables are considered more important or are weighted more heavily than the others. Conversely, the accidents were initially classified by traffic context and critical actions only because this procedure served to structure the sample of cases (albeit crudely) in terms of function failures, causal factors, and operator characteristics.

Classification by Function Failure

The next step in the procedure was to subdivide the cases within each group into mutually exclusive *sets* based upon the type of function failure that led to the critical actions. Although the function failures of both operator-vehicle units were considered, the cases were usually grouped in terms of the function failure of the culpable vehicle-operator unit. Therefore, cases were classified into the same set only if they were similar with respect to all of the following attributes:

- The traffic context in which the accident occurred,
- The critical actions of both vehicles, and
- The function failure of the culpable vehicle-operator unit.

Classification by Causal Factors

The third step was to subdivide the *sets* into mutually exclusive *subsets* based on the pattern of causal factors that contributed to the function failure. The factors leading to the function failure of the culpable vehicle-operator unit were always considered when subdividing the sets; in some instances, the cases were further subdivided in terms of the factors that led to the function failure of the non-culpable vehicle-operator unit.

This procedural step was more difficult to accomplish than the first two because of the difficulty in identifying the full complement of causal factors. Even under the best of circumstances, it is difficult to ferret out all of the factors that contributed to a function failure. The task was made even more difficult when it was not possible to interview one of the operators, when one of the operators was very young (the bicyclist), or when one or both operators were highly defensive about his or her role in the accident. So, it must be emphasized that the classification performed in Step Three was based on *known* factors.

When the factors contributing to the function failure could not be identified with a reasonable degree of confidence, the case was classified into an "unknown" subset. Otherwise, cases classified into the same subset were similar with respect to:

- The traffic context in which the accident occurred,
- The critical actions of both vehicles,
- The function failure of the culpable vehicle-operator unit, and
- The pattern of causal factors that contributed to the function failure of the culpable vehicle-operator unit or, in some cases, both vehicle-operator units.

Functional Grouping of Subsets

Accidents that involve a similar target group and that are amenable to the same specific countermeasures can be considered *functionally* the same even though the accidents may not be identical in every respect. Thus, the purpose of the fourth step was to examine the similarities and differences among subsets and to group together those that were *functionally* similar.

The relevancy of the similarities and differences among subsets was evaluated for engineering countermeasures (environmental and vehicular modifications), educational countermeasures (knowledge enhancement, skill enhancement, and attitude modification), and enforcement countermeasures (law generation/modification, enforcement, and adjudication/sanctioning). Subsets were assumed to be amenable to the same specific countermeasures when the specific countermeasures objective of each subset was the same and when there were no important differences among the subpopulations of operators. Judgments about the amenability of subsets to the same countermeasures were made without regard to the availability of a known technique for achieving the specific countermeasures objective.

The fundamental grouping of subsets was complicated by the fact that a subset often had two or more promising solutions. That is, a subset might have an engineering solution, an educational solution, and an enforcement solution; or the subset might have two or more entirely different solutions of the same class, such as two or more educational solutions. When comparing two subsets, each with more than one solution, it was frequently found that the subsets had one common solution but seldom more than one. For instance, two subsets may be amenable to the same specific educational solution but would require altogether different engineering solutions. *The implication of this finding is that there is no single functional grouping that is optimal for engineering countermeasures, educational countermeasures, and enforcement countermeasures.*

Definition of Problem Classes, Types, and Subtypes

Ideally, study of the accident cases judged to be functionally the same would enable one to formulate a definition of an "average case" that embodies all of the germane attributes of every case in the functional group. Although the cases may differ in many respects, the differences would be irrelevant for countermeasures identification and assessment. The description of the "average case" would serve to define a problem type.

In reality, it is impossible to define an acceptably small number of *pure* problem types because of the complication described above. Using subsets of cases (as defined in Step Three) as the basis for defining problem types would result in an excessive number of problem types. Using functionally similar subsets as the basis for defining problem types would result in an acceptably small number of types, but the types would be less pure because the cases in the same functional group may differ in attributes that *are* important for countermeasures identification and assessment. For example, the differences among cases may be irrelevant when considering educational countermeasures, but may be critically important when considering engineering or enforcement countermeasures.

It was concluded that the only meaningful solution to this problem was to develop a hierarchical system that is composed of problem *classes*, *types*, and *subtypes*. Problem classes reflect commonality at the most general level. Although accidents of the same class are similar with respect to some of their attributes, they may differ in ways that have important implications for countermeasures identification. Problem types represent variations of accidents of the same class, and subtypes represent variations of accidents of the same type. The system was developed so that the problem types generally provide the most useful definition of a problem for which specific countermeasures can be tailored. In some cases, however, an entire class or a specific subtype may best serve as a problem definition for the identification of some types of countermeasures.

The classification system finally decided upon is defined and discussed in considerable detail in Section V of this report. Some readers undoubtedly will find that a different ordering of subtypes would have suited their purpose better. Hopefully, the data are presented in sufficient detail to enable the interested reader to reorder the subtypes and to estimate the frequency of occurrence of new "problems" defined in this way.

DATA ANALYSIS

Data were tabulated and analyzed for selected data items from the *Descriptive Data Form*, the *Bicyclist Interview Form*, the *Motorist Interview Form*, and the *Refusal Form*. Data were analyzed for the pooled sample and by accident class, type, and subtype. The general objectives of the analyses are listed below.

- Evaluate the representativeness of the sample of accidents compiled during the study.
- Describe the important characteristics of the sample of operators, their vehicles, the accident location, and the accident consequences.
- Determine the relative frequency of occurrence for the various problem classes, types, and subtypes.
- Determine if urban accidents differ in type and/or relative frequency from rural accidents.
- Determine if there are problem classes, types, or subtypes that account for a disproportionate number of fatal injuries.

COUNTERMEASURES IDENTIFICATION

An attempt was made to compile an exhaustive inventory of countermeasures for each problem type and to identify for each type the countermeasures that appeared most promising. This was a highly judgmental task that was performed within the constraints of existing information about potential countermeasure approaches and their relative effectiveness. The general categories of countermeasures that were considered include education, enforcement, and engineering.

SECTION IV
RESULTS OF DESCRIPTIVE ANALYSIS

This section presents the major findings of the analysis of the descriptive data compiled during the course of this study. Separate subsections are devoted to the description and discussion of the size and composition of the sample, the characteristics of the operators, the characteristics of the accident vehicles, the characteristics of the trip the operators were on when the accident occurred, the characteristics of the accident site, the consequences of the accident, and the accident causes. The data presentation is preceded by a brief description of the manner in which projections of the population parameters may be made from the reported percentage values.

Throughout this section, the descriptive data that were compiled in this study have been compared with similar data from other studies reported in the literature. In some instances, the purpose of the comparison is to determine whether the operators in the accident sample differ in any important respects from the general population of operators. In most instances, however, the purpose of the comparison is to determine whether the sample of accident cases selected for this study is reasonably representative of the bicycle/motor-vehicle accidents that occur throughout the United States.

CONFIDENCE INTERVALS

Each of the percentage values reported in this section can be taken to represent an estimate of a population parameter. Since all such statistics are subject to sampling error, it is necessary to consider the size of the sampling error when making inferences about the population from which the survey sample was drawn. Computation of confidence intervals based on the standard error of a measurement is probably the most common and meaningful technique used to assess the reliability of a sample statistic. The computation of the standard error[6] of a percentage value is a relatively easy task, but it is not practical to report and discuss confidence intervals for each of the hundreds of percentage values presented in this report. It is, however, recognized that readers may wish to know the confidence intervals for certain percentage values that are of particular interest to them. Therefore, Figure 5 was prepared to provide a quick approximation of the size of the confidence interval for most percentage values contained in the data presentation.

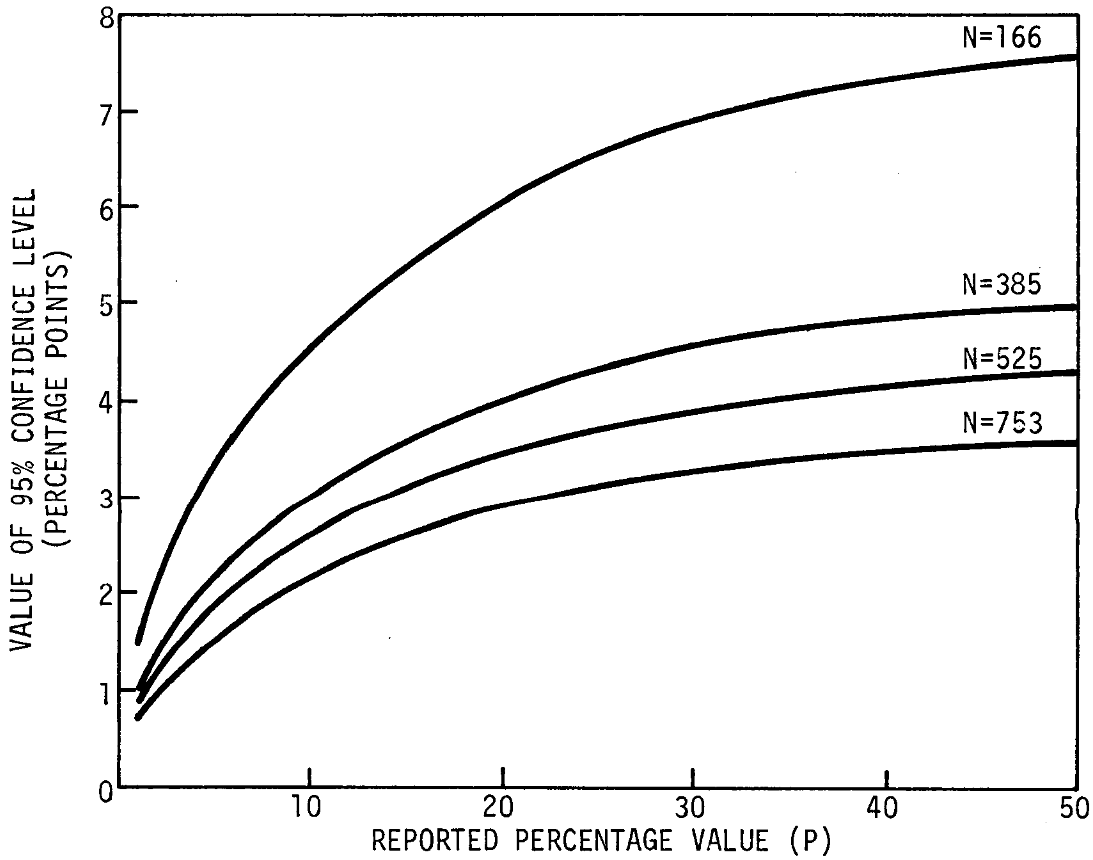

Figure 5. Value of 95% confidence interval for reported percentage values (P) as a function of sample size (N).

[6]The accepted formula for the standard error of a percentage is $\sqrt{PQ/N}$, where P is the percentage of interest, Q = 100-P, and N is the number of cases on which P and Q are based. The 95% and 99% confidence intervals are represented by $P\pm1.96\sigma$ and $P\pm2.58\sigma$, respectively, where σ is the standard error of P.

Figure 5 shows the 95% confidence interval for a percentage value as a function of the four most common *base* N's on which the reported percentages are based--the number of fatal cases (N = 166), the number of non-fatal cases (N = 753), the number of motorists interviewed (N = 385), and the number of bicyclists interviewed (N = 525). Thus, the 95% confidence interval can be determined by reading the ordinate value corresponding to the intercept of the appropriate plotted curve and a vertical line drawn from the appropriate percentage value on the abscissa. For example, if 30% of the cases in a sample of 385 were reported for a category of interest and the reader wished to know the confidence interval for that percentage, it would be found by drawing a vertical line from a value of 30% on the abscissa to the plotted curve labeled "N = 385." The ordinate value corresponding to this intercept is 4.6%, so the 95% confidence interval is 30% ± 4.6%.

THE SAMPLE

TOTAL SAMPLE SIZE

The total number of fatal and non-fatal cases included in the sample and the number of cases drawn from each sampling area are shown in Table 2. It can be seen that a total of 753 non-fatal cases and 166 fatal cases were investigated, and that the non-fatal cases were drawn from each of the four sampling areas in approximately equal numbers.

TABLE 2

NUMBER OF ACCIDENT CASES DRAWN FROM EACH SAMPLING AREA

SAMPLING AREA	FATAL N	FATAL %	NON-FATAL N	NON-FATAL %
CALIFORNIA	77	*46.4*	177	*23.5*
COLORADO	2	*1.2*	178	*23.6*
FLORIDA	65	*39.2*	232	*30.8*
MICHIGAN[1]	22	*13.3*	166	*22.1*
TOTAL	166	*100*	753	*100*

[1]Includes one fatal case and 27 non-fatal cases investigated in Maryland.

Only 55 fatal accidents occurred within the primary sampling areas and all of these cases were included in the sample. To increase the size of the fatal sample, accident reports were obtained for all the fatal accidents that occurred during calendar year 1975 throughout the entire States of Florida and California. Thus, the fatal cases for Colorado and Michigan include only the accidents that occurred within the sampling area, whereas the fatal cases for California and Florida include the accidents that occurred throughout the entire state.

NUMBER OF INTERVIEWS COMPLETED

Non-Fatal Cases

It will be recalled that a non-fatal accident case was included in the sample only if at least one of the operators agreed to be interviewed. For this reason, at least one operator interview was completed for all 753 non-fatal cases. Table 3 shows the relative proportions (for the non-fatal sample) of all motorists and bicyclists who were interviewed, who refused to be interviewed, and who were not contacted by the Field Investigator. It can be seen that about 70% of the bicyclists and 51% of the motorists were interviewed. The difference in the relative proportions of bicyclists and motorists interviewed was due to a higher incidence of refusals by motorists (18.9% vs. 9.6%) and greater difficulty in establishing contact with motorists than bicyclists (30% vs. 20.7%).[7]

TABLE 3

NUMBER OF OPERATORS WHO WERE CONTACTED AND WHO AGREED/REFUSED TO BE INTERVIEWED

		BICYCLIST N	BICYCLIST %	MOTORIST N	MOTORIST %
OPERATOR CONTACTED	INTERVIEWED	525	*69.7*	385	*51.1*
	REFUSED INTERVIEW	72	*9.6*	142	*18.9*
OPERATOR NOT CONTACTED		156	*20.7*	226	*30.0*

[7] The refusal *rate*--the proportion of operators *contacted* who refused to be interviewed--was 12.1% for the bicyclists and 26.9% for the motorists.

Failure to contact the involved operator was usually because the Field Investigator was unable to obtain a current address or phone number for the operator. In some cases, however, the operator's residence was located so far outside the sampling area that no attempt was made to arrange an interview. The distant location of the motorists' residences is the main reason for the difference in the number of motorists and bicyclists who were contacted.

About five percent of the bicyclist refusals was because the bicyclist had not yet recovered sufficiently from severe injuries sustained in the accident. About 12% of both the bicyclists and motorists who refused the interview were advised to do so by their legal counsel because of pending litigation. The remaining bicyclists and motorists who refused the interview did so because of scheduling difficulties or because they simply did not wish to be inconvenienced.

Operators who refused the interview were compared with the other operators in the sample[8] in terms of their age, sex, and culpability. The differences revealed by the comparison are summarized below.

- Bicyclists who refused the interview tended to be younger than the other bicyclists in the sample, but the difference in the median age for the two groups was only .7 year.
- The motorists who refused the interview were slightly older than the other motorists in the sample. The difference in the median age for the two groups was 3.7 years.
- Significantly more female motorists than male motorists refused to be interviewed ($\chi^2 = 6.72$, $p < .01$). Forty-five percent of the motorists who refused the interview were females, while only 33% of the other motorists in the sample were female. Female bicyclists, however, were no more likely to refuse the interview than were male bicyclists.
- Significantly more culpable bicyclists than non-culpable bicyclists refused to be interviewed ($\chi^2 = 7.30$, $p < .01$). Eighty-five percent of the bicyclists who refused the interview were judged culpable,

[8]The operators who were not contacted did not differ in any important respect from those who were contacted and agreed to be interviewed. For this reason, the two groups were combined for comparison with operators who refused to be interviewed.

while only 78% of the other bicyclists were judged culpable. Surprisingly, it was found that culpable motorists refused to be interviewed no more frequently than non-culpable motorists.

When only one operator could be interviewed, an attempt was made to interview persons who witnessed the accident. One or more witnesses were interviewed for 131 of the non-fatal cases. This number does not include eight cases in which interviews were conducted with the parents of a young bicyclist.

Fatal Cases

For all fatal cases that occurred within the sampling areas (N = 55), the Field Investigators were instructed to attempt to arrange an interview with the motorist, the parents of the deceased bicyclist, and persons who witnessed the accident. The Field Investigators were uniformly unsuccessful in their attempts to interview any of the parties to the fatal accidents. Complete face-to-face interviews were conducted with only two motorists, ten witnesses, and the parents of five deceased bicyclists. Most of the parties to fatal accidents refused the interview because they did not wish to resurrect the memory of an extremely traumatic experience. The motorists' reluctance to be interviewed was further compounded by the fact that litigation was pending in about one-third of the fatal accident cases.

Fortunately, the lack of interview data for fatal cases was partially offset by the increased amount of information contained in the official traffic accident report. With only a few exceptions, the traffic accident reports for fatal cases were far more detailed and precise than the reports for non-fatal cases. The information contained in the official report was nearly always detailed enough to enable an assessment to be made of the function failure that precipitated the accident. In some cases, the official report contained information about the factors that contributed to the function failures.

For all practical purposes, the information compiled for fatal cases was limited to that available on the traffic accident report (166 cases) and that obtained from site investigation for the 55 cases which occurred within the sampling areas.

THE OPERATORS

The data presented in this subsection serve to describe the characteristics of the vehicle operators--the bicyclists and the motorists. The operator characteristics discussed below include: age, sex, driving experience, familiarity with the vehicle, familiarity with the accident site, and physical and mental condition at the time of the accident.

OPERATORS' AGE

Bicyclists' Age

The age distributions of the fatally injured and non-fatally injured bicyclists in the study sample are shown in Figure 6. It should be noted that accident frequency is plotted for two-year age intervals. Thus, the first point represents the percentage of bicyclists in the sample whose age was four or five; the second point represents the percentage of bicyclists whose age was six or seven; and so on. Beginning at age four, accident frequency rises steadily to the age of 12 and remains at this high level through the age of 15. Thereafter, accident frequency declines dramatically and remains at a relatively low and constant level for ages beyond 30 years.

The general shape of the curves for fatal and non-fatal accidents is similar, but fatal accidents are more frequent among the very young and the very old bicyclists. About 4.5% of the fatal cases involved a bicyclist younger than six years of age, while only two percent of the non-fatal cases involved a bicyclist younger than six years. Similarly, it can be seen that 18.2% of the fatal cases involved a bicyclist older than 35 years of age, while only 4.2% of the non-fatal cases involved a bicyclist older than 35 years. Although not shown in Figure 6, over ten percent of the fatalities involved a bicyclist older than 55 years, and three percent involved a bicyclist older than 75 years of age.

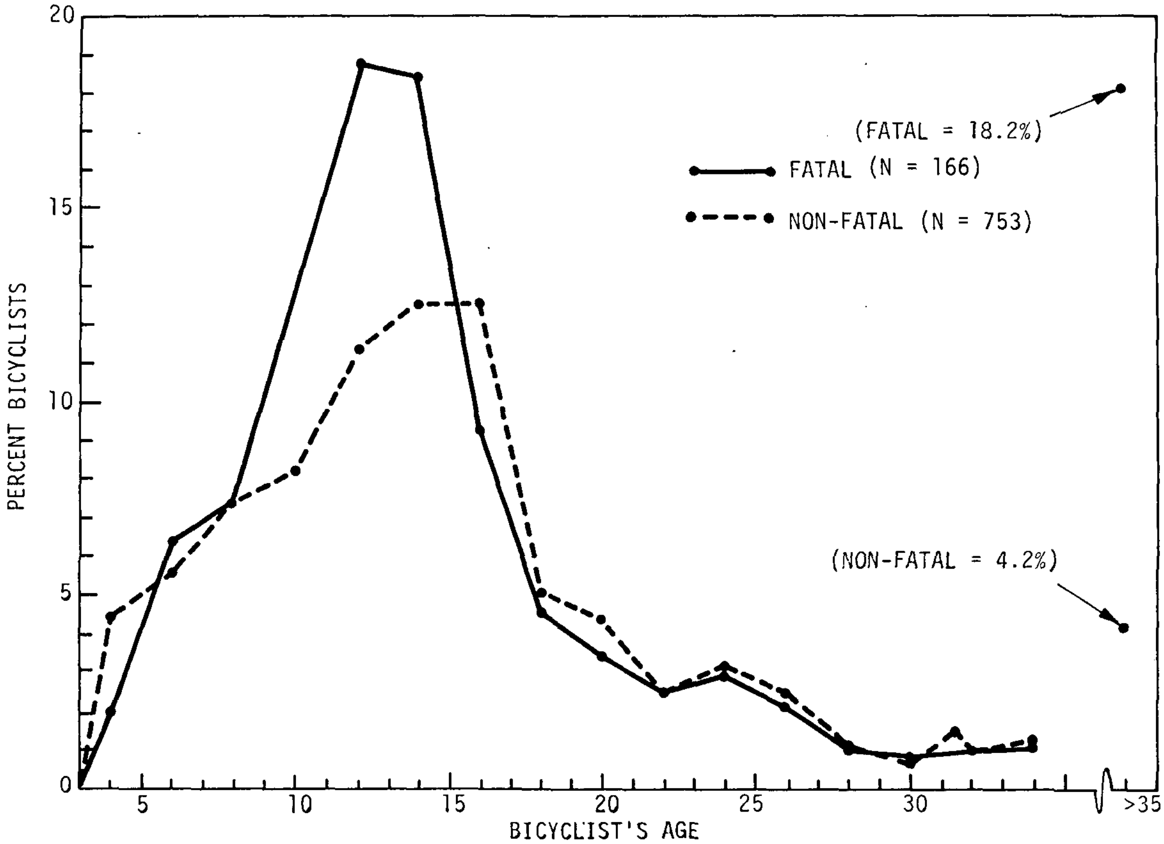

Figure 6. Bicyclist age distributions for fatal and non-fatal accident cases in the study sample.

Each year, the National Safety Council reports the age distribution of a nationwide sample of bicyclists who were involved in a bicycle/motor-vehicle accident during the preceding year. Comparison of the age distribution of the bicyclists in the study sample with the bicyclist age distribution reported by the National Safety Council (for the same calendar year) provides an indication of the representativeness of the study sample. Figure 7 shows the bicyclist age distribution for the study sample and for the National Safety Council's sample of bicycle/motor-vehicle accidents that occurred during calendar year 1975 (National Safety Council, 1976). It can be seen that the same general trend is exhibited by both distributions and that the percentage values for most age intervals are similar. None of the differences between percentage values for the fatal cases

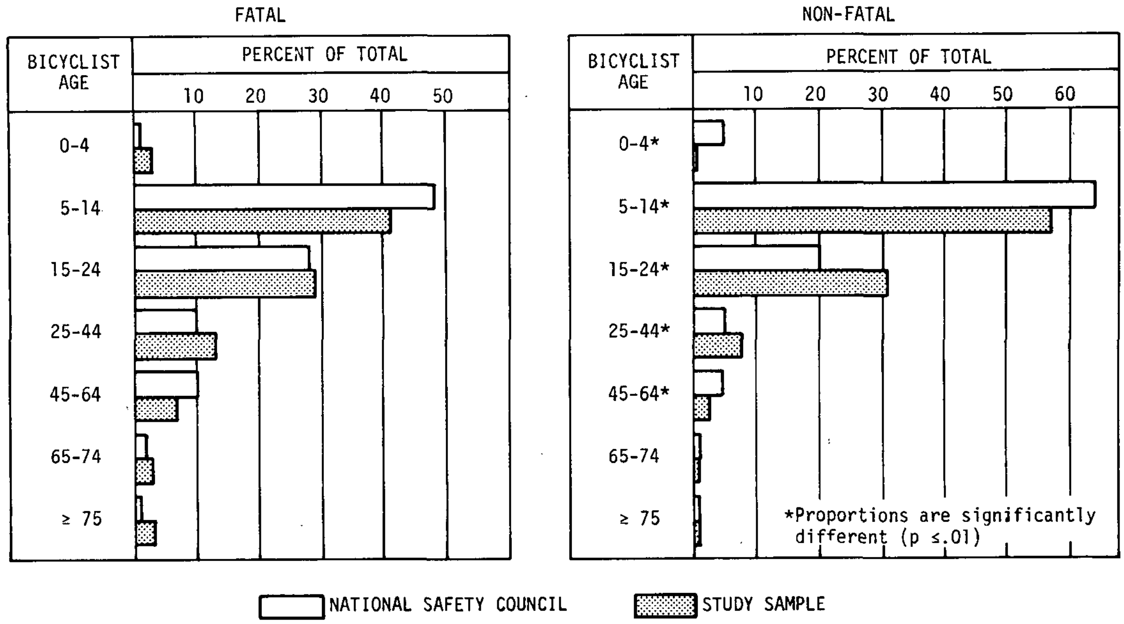

Figure 7. Age distribution of bicyclists in the study sample compared with the bicyclist age distribution reported by the National Safety Council.

proved to be statistically significant,[9] while the differences for the first five age intervals (through age 64) were statistically different for the non-fatal accidents. The largest bias in the study sample was an underrepresentation of bicyclists in the five to 14 year age group and an overrepresentation of bicyclists in the 15 to 24 year age group. The most probable explanation for these differences is that the study sample contained a proportionately greater number of rural accidents than did the

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[9]The following formula was used to assess the significance of differences between proportions (Guilford, 1965).

$$\bar{z} = \frac{p_1 - p_2}{\sqrt{\bar{p}_e \bar{q}_e \left(\frac{N_1+N_2}{N_1 N_2}\right)}}$$

where: $\bar{p}_e = \frac{N_1 p_1 + N_2 p_2}{N_1 + N_2}$

$\bar{q}_e = 1 - \bar{p}_e$

N_1 = Total N on which p_1 is based

N_2 = Total N on which p_2 is based

National Safety Council sample; rural accidents involve more older riders (on the average) than urban accidents. While there is a statistically reliable bias in the ages of the bicyclists in the study sample, the magnitude of the bias is not large enough to invalidate the results of this study. The bias will result in a slight underestimation of relative frequency of problem types that typically involve juvenile riders and an overestimation of the frequency of problem types that typically involve young adults. However, the bias should add less than one percent to the error of estimates for a given problem type.

It is of interest to note that the age distributions shown in Figure 7 are quite similar to the age distributions shown in a number of other accident studies, including studies by: the Automobile Association (1972), the California Highway Patrol (1974), the Virginia Department of Highways (1974), Walsh and Watt (1974), and the Washington State Patrol (1973).

The age distribution of bicyclists in an accident sample is most meaningfully evaluated in terms of the relative exposure for each age group. Although exposure data are not available that take into account the combined frequency and amount of bicycle usage for each age group, Barton Aschman and Associates conducted statewide household surveys to assess the relative proportion of persons within each age group who rode a bicycle at least once during the year preceding the interview. Separate surveys were conducted for the State of Tennessee (Barton Aschman, 1974) and the State of Pennsylvania (Barton Aschman, 1975). The age distributions revealed by these surveys are shown in Table 4, along with corresponding age distributions for the fatally-injured and non-fatally-injured bicyclists in the study sample. Also shown in Table 4 is the age distribution for the combined samples obtained in the States of Tennessee and Pennsylvania.

An analysis was performed to determine whether the age distribution for either the fatal or non-fatal sample differed significantly from the age distribution of the user population--as measured by the combined sample for Tennessee and Pennsylvania (see column five of Table 4). In columns one

TABLE 4

COMPARISON OF AGE DISTRIBUTIONS FOR ACCIDENT SAMPLE
AND THE GENERAL BICYCLING POPULATION

	ACCIDENT SAMPLE		BICYCLE USERS[1]		
BICYCLIST AGE	FATAL (N=166)	NON-FATAL (N=753)	TENNESSEE (N=3141)	PENNSYLVANIA (N=6372)	COMBINED[2] (N=9513)
< 6	4.2%	*2.0%	5.9%	4.5%	5.0%
6-11	20.6%	*27.5%	25.9%	23.0%	24.0%
12-15	23.1%	*37.1%	17.1%	19.0%	18.4%
16-19	16.9%	13.9%	11.5%	12.2%	12.0%
20-29	13.4%	*12.2%	17.4%	15.8%	16.3%
30-44	*8.5%	*3.8%	15.8%	16.7%	16.4%
45-59	5.4%	*1.8%	6.3%	7.3%	7.0%
≥ 60	*7.9%	1.7%	1.2%	1.2%	1.2%

[1]User data from household surveys completed by Barton-Aschman Associates, Inc., for the Tennessee Departments of Conservation and Transportation (Barton-Aschman, 1974) and the Pennsylvania Department of Transportation (Barton-Aschman, 1975).

[2]Combined percentage = $\frac{P_1N_1 + P_2N_2}{N_1 + N_2}$

*Proportion differs significantly from the proportion of users (combined Tennessee and Pennsylvania samples) in the corresponding age group ($p < .05$).

(FATAL) and two (NON-FATAL), asterisks were placed beside the percentage values that differed significantly from the corresponding percentage value in column five (user population).

An examination of the data for the fatal sample shows that bicyclists younger than 30 years of age and those between 45 and 59 years of age are involved in fatal accidents in about the same proportion as their numbers in the user population. Bicyclists between 30 and 44 years of age are involved in fatal accidents significantly *less* often than would be expected from their numbers in the user population; bicyclists 60 years of age or older are involved in fatal accidents significantly *more* often than would be expected from the proportion of persons in this age group who ride bicycles. Stated differently, these data suggest that the likelihood of being killed in a bicycle/motor-vehicle accident is *less* for bicyclists in the 30-44 age group, and greater for bicyclists who are 60 years old or older.

Examine next the age distribution for the non-fatal sample. It can be seen that bicyclists between six and 15 years of age are involved in non-fatal accidents more often than would be expected from their numbers; bicyclists younger than six years of age and those between 20 and 59 years of age are involved less often than would be expected from their numbers in the user population. It is of particular importance to note that:

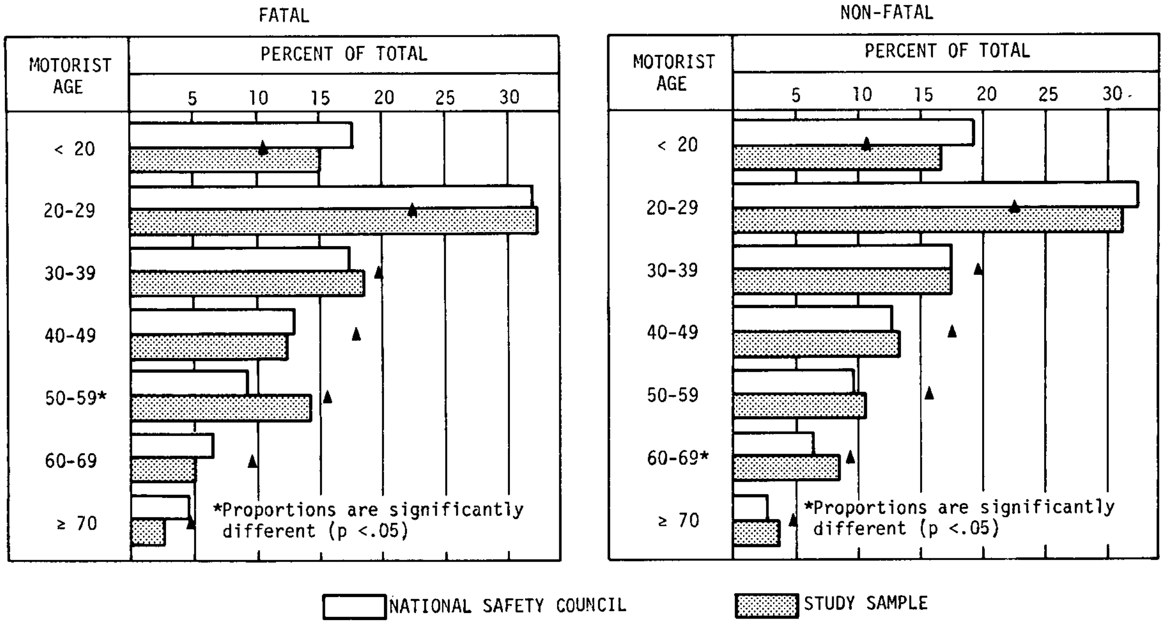
- Accident involvement among 12-15 year old bicyclists is more than twice as great as would be expected from the number of bicycle users in this age group.
- Accident involvement of bicyclists between 30 and 59 years of age is less than one-fourth of that expected from the number of bicyclists in this age group.

Except for the youngest age group, conclusions about the likelihood of accident involvement for different age groups would not be affected by the biased age distribution for the non-fatal accident sample (see Figure 7). In fact, the trends shown in Table 4 would be amplified by removing the sampling bias.

Motorists' Age

The age distributions of motorists in the fatal and non-fatal samples are shown in Figure 8. Also shown for comparison purposes is a) the age distribution of motorists involved in all types of traffic accidents (National Safety Council, 1976) and b) the proportion of all licensed drivers in the corresponding age group.

It can be seen that the age distribution of motorists involved in bicycle/motor-vehicle accidents is highly similar to the age distribution of motor-vehicle operators involved in all types of traffic accidents. Only two differences proved to be statistically significant. Motorists in



The triangles (▲) show the proportion of all licensed drivers in the corresponding age group.

Figure 8. Age distribution of motorists in the study sample compared with the age distribution of motorists involved in all types of traffic accidents (National Safety Council, 1976).

the 50 to 59 year age group are involved in fatal accidents more often than would be expected from their numbers, and motorists in the 60-69 year age group are involved in non-fatal accidents more often than would be expected from their numbers. Although statistically significant, these differences are not large enough to have important implications for countermeasures development. Therefore, for all practical purposes, it can be assumed that the age of motorists who are involved in bicycle/motor-vehicle accidents is distributed the same as for motorists who are involved in all other types of traffic accidents.

OPERATORS' SEX

The vehicle operators in the study sample--both bicyclists and motorists--were predominantly males. Figure 9 shows that male *bicyclists* were involved in 71% of the non-fatal cases and 85% of the fatal cases; male *motorists* were involved in 65% of the non-fatal cases and 72% of the fatal cases. The percentage of male bicyclists was significantly greater

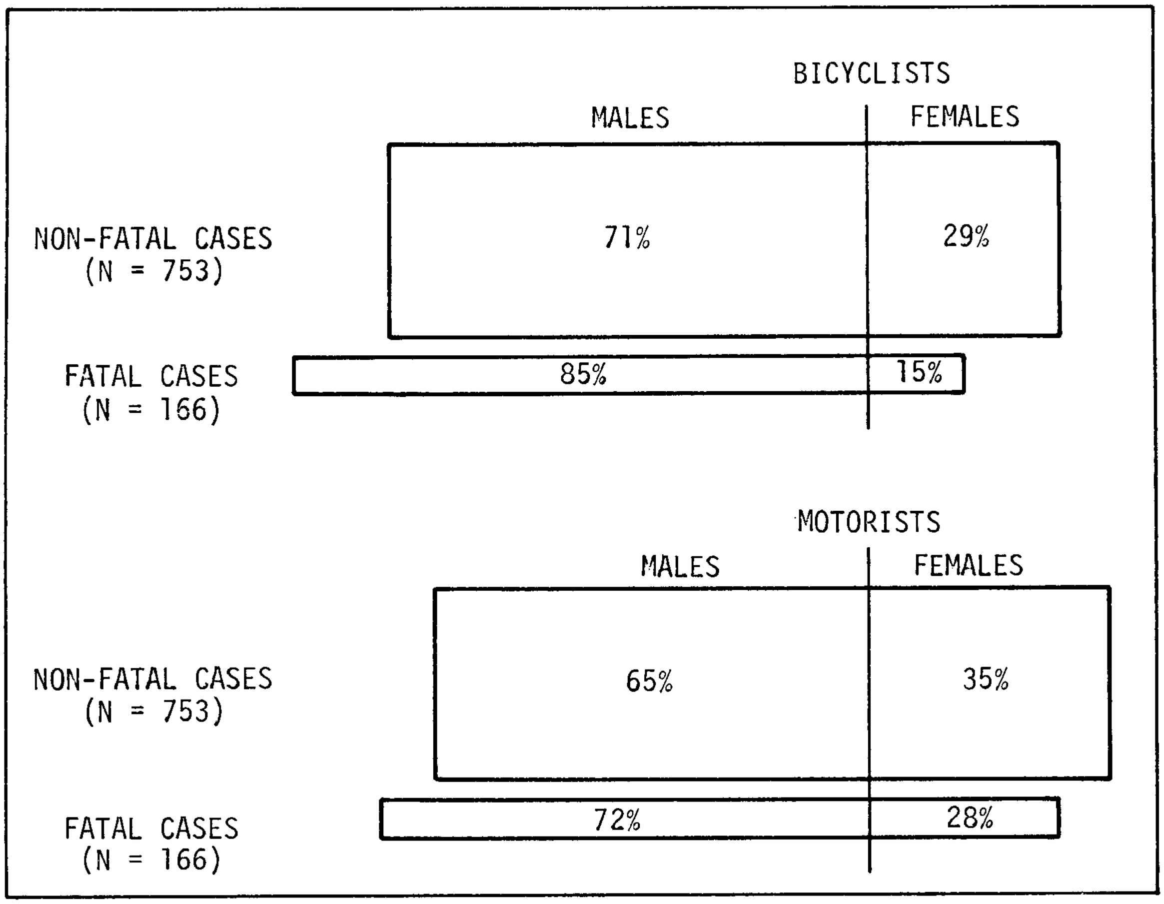


Figure 9. Distributions of males and females for fatal and non-fatal cases.

NOTE: The National Safety Council reports that 83% of the drivers involved in fatal accidents are males and that 71% of the drivers involved in non-fatal accidents are males (National Safety Council, 1976).

($p < .01$) for the fatal than the non-fatal sample, but the difference in the percentage of male motorists for the fatal and non-fatal samples was not statistically significant.

An overrepresentation of male operators is not unique to bicycle/motor-vehicle accidents. The National Safety Council reports that male drivers are involved in 83% of all fatal and 71% of all non-fatal traffic accidents (National Safety Council, 1976). It is probable that the overrepresentation of male bicyclists is due in large part to differences in exposure. On the average, male bicyclists ride more often, take longer trips, and may tend to ride in more dangerous locations than female bicyclists. However, it is also probable that males and females behave differently when riding a bicycle, and that these behavioral differences have an important impact on the likelihood of involvement in a bicycle/motor-vehicle accident. Unfortunately, the literature contains so little data on the bicycle usage patterns of male and female bicyclists that it is impossible to offer a reliable explanation for the overrepresentation of males in bicycle/motor-vehicle accidents.

DRIVING/RIDING EXPERIENCE

During the interviews, the operators were asked to indicate the number of years they had been driving/riding regularly prior to the time the accident occurred. The main purpose of this subject of inquiry was to identify novice motorists and bicyclists. Figure 10 shows the centiles of the driving/riding-experience distributions for motorists and bicyclists. While the overall range of experience was far greater for motorists than for bicyclists, it can be seen that the study sample contained more novice motorists than novice bicyclists. Note that more than five percent of the motorists in the sample had less than one year driving experience when the accident occurred, while the riding experience of the fifth centile bicyclists was about one and one-half years.

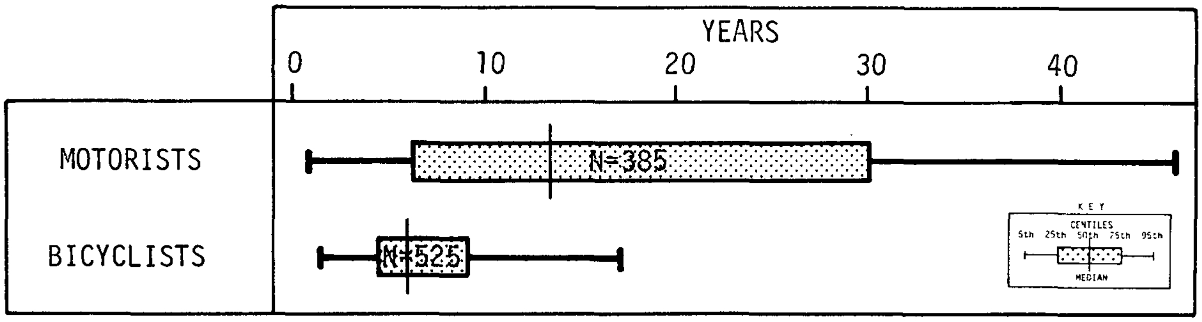


Figure 10. Distribution of driving/riding experience among motorists and bicyclists in the study sample of non-fatal accidents.

Although an operator may have learned to drive or ride many years ago, it is possible that he drives or rides too infrequently to maintain a reasonable level of vehicle-handling skills. To identify operators whose vehicle-handling skills may have been deficient because of infrequent vehicle usage, the operators were asked to indicate the number of hours spent operating their vehicle during a typical week for the 12-month period before the accident occurred. The distributions for motorists and bicyclists in the non-fatal study sample are shown in Figure 11. It will be noted that the sample contained very few persons who operate a vehicle only rarely. For example, even the fifth centile motorists and bicyclists operate their vehicles 2.1 and 3.3 hours per week, respectively.

No data have been located that indicate the amount of driving/riding experience that is required to acquire and maintain a reasonable level of vehicle-handling skills. However, it seems reasonable to assume that a relatively high level of vehicle-handling skills can be acquired by most persons in about one year and that these skills can be maintained by operating a vehicle for one or two hours each week. If these conclusions are valid, it can be concluded that few motorists and bicyclists in the non-fatal study sample lacked basic vehicle-handling skills at the time the accident occurred.

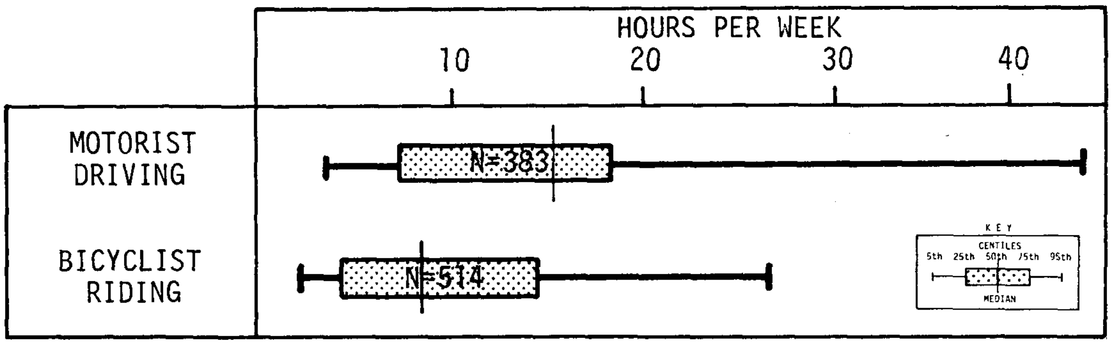


Figure 11. Distribution of hours spent driving/riding during a typical week by motorists/bicyclists in the study sample of non-fatal accidents.

FAMILIARITY WITH ACCIDENT VEHICLE

During the interview, bicyclists and motorists were asked to indicate the number of times they had ridden/driven the accident vehicle before the day of the accident. Table 5 shows that about 75% of the bicyclists and about 93% of the motorists had ridden/driven the accident vehicle at least 50 times before the accident occurred and were, therefore, thoroughly familiar with that vehicle.

TABLE 5

DISTRIBUTION OF TIMES OPERATOR HAD DRIVEN/RIDDEN THE ACCIDENT VEHICLE PRIOR TO THE DAY OF THE ACCIDENT (NON-FATAL ACCIDENT SAMPLE)

TIMES OPERATED VEHICLE BEFORE ACCIDENT	BICYCLIST N	BICYCLIST %	MOTORIST N	MOTORIST %
0-4	40	7.5	10	2.6
5-9	15	2.9	3	.8
10-19	29	5.5	6	1.6
20-29	25	4.8	4	1.0
30-39	15	2.9	2	.5
40-49	9	1.7	3	.8
≥ 50	392	74.7	357	92.7
TOTAL	525	100	385	100

There is no information about the number of times an operator must operate a vehicle before he becomes thoroughly familiar with it; but, even if it is assumed that as many as 20 times are required, the data show that there was a relatively small number of operators who were riding/driving an unfamiliar vehicle at the time the accident occurred. It can be seen that only about 16% of the bicyclists and five percent of the motorists had ridden/driven their vehicle less than 20 times before the day of the accident.

Each operator was asked whether lack of familiarity with his vehicle contributed to the accident in any way. An affirmative answer to this question was given by 5.5% of the bicyclists and 1.6% of the motorists. Of the bicyclists who responded affirmatively to this question, about 41% indicated that they were riding a borrowed or new bicycle at the time the accident occurred, and about 38% indicated that they were unfamiliar with the operation of hand brakes. Over one-third of the motorists who responded affirmatively were motorcyclists who were unfamiliar with the operation of motorcycle hand brakes.

FAMILIARITY WITH ACCIDENT SITE

Table 6 shows the distribution of times the operators had driven through the accident site before the day of the accident. It can be seen that the vast majority of accidents occurred at a location that both operators had driven through many times prior to the accident. Only 16.6% of the bicyclists and 5.2% of the motorists had driven through the accident site fewer than five times prior to the accident. In contrast, 62.4% of the bicyclists and 83.6% of the motorists had driven through the accident site 50 or more times before the accident.

TABLE 6

DISTRIBUTION OF TIMES OPERATOR HAD DRIVEN/RIDDEN THROUGH THE ACCIDENT SITE PRIOR TO THE DAY OF THE ACCIDENT (NON-FATAL ACCIDENT SAMPLE)

TIMES THROUGH SITE	BICYCLIST N	BICYCLIST %	MOTORIST N	MOTORIST %
0-4	86	*16.6*	20	*5.2*
5-9	17	*3.3*	12	*3.1*
10-19	30	*5.8*	10	*2.6*
20-29	27	*5.2*	9	*2.3*
30-39	23	*4.4*	11	*2.9*
40-49	12	*2.3*	1	*.3*
≥ 50	324	*62.4*	320	*83.6*
TOTAL	519	*100*	383	*100*

Operators also were asked their opinions about whether lack of familiarity with the accident location contributed to the accident in any way. An affirmative answer was given by 6.9% of the bicyclists and 3.4% of the motorists. Unexpectedly high traffic density and unusual traffic-movement patterns were the most common explanations given for why lack of familiarity with the site contributed to the accident. It is interesting to note that only two bicyclists in the sample and none of the motorists indicated that a lack of familiarity with the type or location of traffic signs/signals contributed to the accident.

As will be discussed in more detail later, many accidents were the direct or indirect result of a suboptimal pre-crash course by one or both vehicles. The findings reported here indicate that few operators selected a suboptimal course through the accident area because they were unaware of the physical or operational characteristics of the traffic environment.

OPERATORS' PHYSICAL AND MENTAL CONDITION

All operators who were interviewed were questioned in detail about their physical and mental condition at the time of the accident. Specifically, operators were questioned about permanent impairments (vision, hearing, limbs, body parts other than limbs, nervous or mental, and other) and temporary impairments (had been drinking, under influence of prescribed drugs, under influence of non-prescribed drugs or narcotics, temporary illness, physical fatigue, emotional stress, and other). For the operators who were not interviewed, information concerning alcohol use was obtained from the official traffic accident report. Information from the official traffic accident report was also used to confirm the reports of operators who *were* interviewed.

The relative frequency with which temporary and permanent impairments were reported by the operators is shown in Figure 12. The number of operators who reportedly had been drinking prior to the accident is shown separately, because information about alcohol use is based upon both self reports by the operators and information obtained from the traffic accident report.

Since the data in Figure 12 are based on self reports by the operators, the values shown are more likely to be underestimates than overestimates of the percentage of operators who were suffering from the impairments at the time of the accident. However, except for non-prescribed drugs/narcotics, admission of the impairments is not severely incriminating. Thus, the response bias should be relatively small for all impairments other than the use of non-prescribed drugs/narcotics. Unfortunately, there is no way to estimate the magnitude of the response bias for drug use from the data compiled during this study.

It can be seen in Figure 12 that the impairments most frequently reported by the *bicyclists* include temporary emotional stress (9.3%),

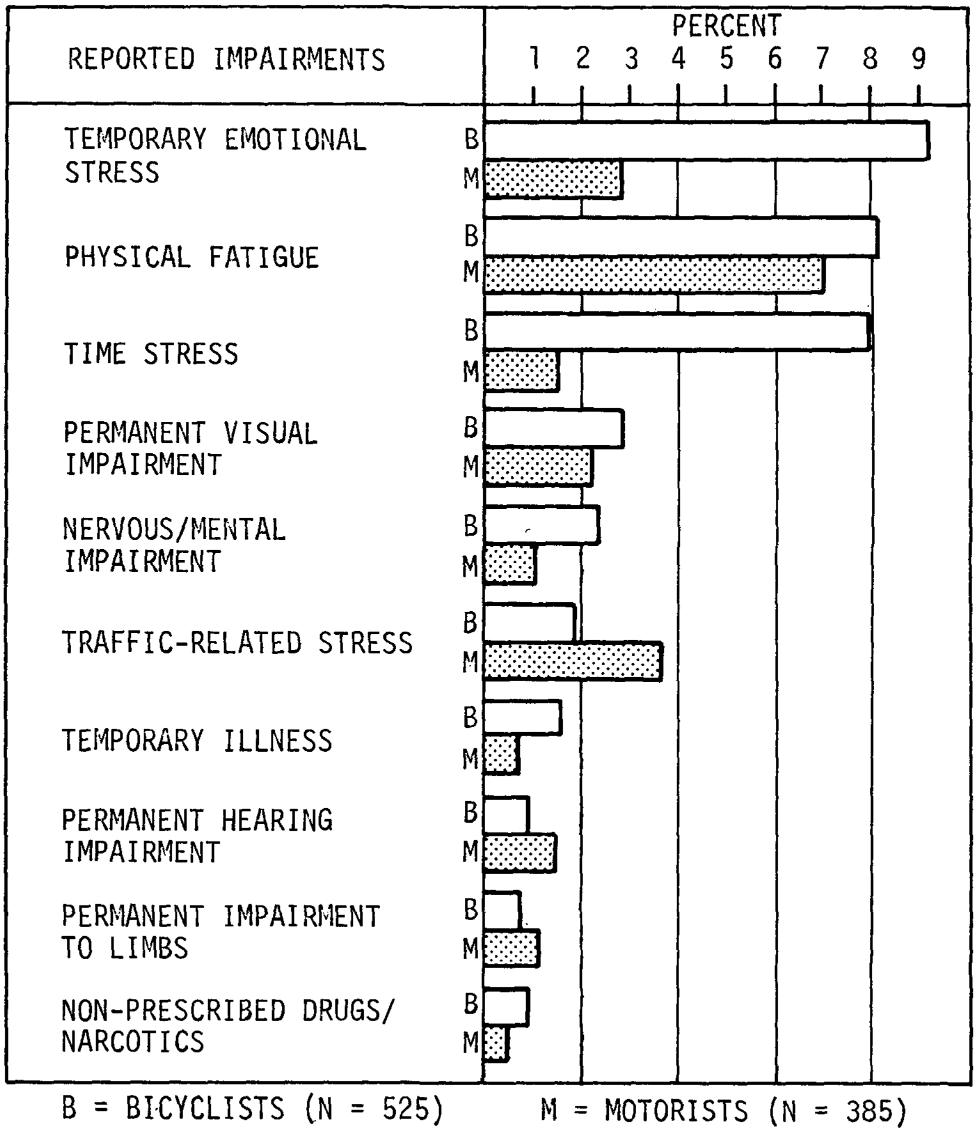


Figure 12. Temporary and permanent impairments reported by operators in the non-fatal accident sample (excluding alcohol use).

physical fatigue (8.2%), and time stress (7.8%). The most commonly reported type of emotional stress was anger stemming from family strife. It is interesting to note that anger stemming from a conflict with a motorist was reported by only two bicyclists in the sample. When physical fatigue was reported by the bicyclist, it was nearly always the result of having completed a long bicycle trip or having just ridden up a steep grade. A few bicyclists reported that their physical fatigue stemmed from a long work day or the lack of sleep. Time stress was usually the result of the bicyclist being late for school, work, mealtime, or another type of appointment. It can be seen that motorists generally reported fewer impairments than bicyclists. Between two and three percent of the bicyclists reported that they were suffering from a visual impairment or a nervous/mental impairment (usually retardation). Less than two percent of the bicyclists reported that they were suffering from any of the remaining impairments listed in Figure 12.

Only four types of impairments were reported by two percent or more of the motorists in the sample: physical fatigue (7.0%), traffic-related stress (3.6%), temporary emotional stress (2.9%), and permanent visual impairment (2.1%).

TABLE 7

NUMBER OF OPERATORS WHO REPORTEDLY HAD BEEN DRINKING PRIOR TO THE ACCIDENT

	NON-FATAL (N=753)		FATAL (N=166)	
	N	%	N	%
BICYCLISTS	6	.8	1	.6
MOTORISTS	26	3.5	28	16.9

Table 7 shows the numbers and proportions of operators in the fatal and non-fatal samples who were judged to be under the influence of alcohol at the time of the accident. This judgment was based upon information from tests administered by the investigating officer, self reports of the operators, and (rarely) information provided by witnesses. Generally, the operator was judged to be under the influence of alcohol if he had consumed the equivalent of two or more drinks within an hour of the accident.

It can be seen that the incidence of alcohol use by bicyclists was relatively low, .8% for non-fatal accidents and .6% for fatal accidents. The incidence of alcohol use among motorists was far greater than for bicyclists, particularly among motorists who were involved in fatal accidents. Table 7 shows that 3.5% of the motorists in the non-fatal sample and 16.9% of the motorists in the fatal sample had been drinking prior to the accident. Although a large proportion of fatal bicycle/motor-vehicle accidents involve alcohol use by the motorist, this percentage is not nearly so high as the percentage of all alcohol-related traffic accidents that result in a fatality (about 50%).

OTHER OPERATOR CHARACTERISTICS

Listed below are other items of information obtained from the interviews with operators in the non-fatal sample. The percentages reported are based on 525 bicyclist interviews and 385 motorist interviews.

- Nineteen percent of the bicyclists and 54% of the motorists reported that they had received formalized training in the operation of a motor vehicle prior to the accident.

- Fifty-seven percent of the bicyclists and 52% of the motorists reported that they had read the laws and ordinances governing bicycles prior to the time the accident occurred.

- Twenty-one percent of the bicyclists and 96% of the motorists possessed a valid motor-vehicle operator's license at the time of the accident. Most of the motorists who did not possess a valid motor-vehicle operator's license were juveniles who were riding motorcycles at the time of the accident.

- Six percent of the bicyclists reported that they ride a bicycle as part of their job (does not include commuting).

- Twenty-five percent of the motorists reported that they drive a motor vehicle as part of their job (does not include commuting).

- Eight percent of the bicyclists reported that they had received some form of formalized training in operating a bicycle prior to the accident.

- Forty-one percent of the bicyclists reported that they commute to school or work on a bicycle.

- Seventeen percent of the motorists reported that they ride a bicycle at least occasionally.

- Eight percent of the bicyclists and one percent of the motorists reported having had at least one bicycle/motor-vehicle accident (other than the one that was being investigated) during the past 24 months. Only 27.7% of the "other" bicycle/motor-vehicle accidents were reported to the police.

- Twenty-two percent of the bicyclists reported that they could have chosen an alternate route to their destination that was safer than the route they were on when the accident occurred.

THE VEHICLES

VEHICLE TYPE

In almost every case, the type of motor vehicle involved in the accident was recorded on the official traffic accident report form, but the specific type of bicycle was seldom reported. For this reason, information about motor-vehicle type was available for almost every case in both the fatal and non-fatal samples, whereas information on the bicycle type was available only for the non-fatal cases in which the bicyclist was interviewed. The information compiled on the distribution of bicycle types and motor-vehicle types is described below.

Bicycle Type

The relative frequency with which different types of bicycles were ridden by male and female bicyclists in the non-fatal sample is shown in Table 8. Also shown is the distribution of bicycle types for the combined (male and female) sample. Considering the combined sample, it can be seen that most bicyclists were riding a lightweight bicycle at the time the

TABLE 8

TYPE OF BICYCLE RIDDEN BY MALE AND FEMALE BICYCLISTS IN THE NON-FATAL SAMPLE

BICYCLE TYPE	MALE		FEMALE		COMBINED	
	N	%	N	%	N	%
LIGHTWEIGHT	186	*51.0*	80	*50.3*	266	*50.8*
STANDARD/MIDDLEWEIGHT	148	*40.5*	74	*46.5*	222	*42.4*
HIGHRISE	23	*6.3*	4	*2.5*	27	*5.1*
OTHER	8	*2.2*	1	*.6*	9	*1.7*
TOTAL	365	*100*	159	*100*	524	*100*

accident occurred; and that a smaller, but significant, number were riding a standard or middleweight bicycle. About five percent of the bicyclists were riding a highrise bicycle; and less than two percent were riding another type of bicycle (child tricycle or big wheel,[10] adult tricycle, folding or collapsible bicycle, tandem bicycle, or custom design).

A comparison of the distributions of bicycle type for males and females shows that nearly identical percentages of males and females (about 50%) were riding a lightweight bicycle. A standard or middleweight bicycle was ridden by a slightly larger percentage of females (46.5%) than males (40.5%), whereas a slightly larger percentage of males than females were riding a highrise or "other" type bicycle. Statistical tests revealed that *none* of the differences between corresponding percentage values were statistically significant ($p > .05$). Therefore, these data suggest that there are no important differences in the types of bicycles ridden by male and female accident victims.

There have been few survey studies that attempted to assess the relative number of bicycles of each type that are in use by the general bicycling population. Most surveys that have addressed the issue of bicycle type are limited to only one segment of the population (school-age children, college students, etc.) or are outdated. One recent study has been located that surveyed the general population in Santa Clara County, California (Diridon Research Corporation, 1973). The distribution of bicycle types in use revealed by this survey is shown in Table 9 along with the distribution of bicycle types for the study sample. It can be seen that lightweight bicycles are overrepresented in the accident sample, and that all other bicycle types are underrepresented. Although no data are available on the distribution of bicycle types in use within the

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[10] Accidents involving child tricycles and "big wheels," are clearly underrepresented in this study sample. Discussions with representatives of Dunlap and Associates (Blomberg, 1977) revealed that accidents involving tricycles and big wheels are usually reported as pedestrian accidents. For a large sample of pedestrian accidents that occurred in Los Angeles, it was found that tricycle and big wheel accidents together accounted for about two percent of *all* pedestrian accidents and five percent of all *child* pedestrian accidents.

TABLE 9

DISTRIBUTION OF BICYCLE TYPES FOR THE STUDY SAMPLE (NON-FATAL CASES) AND A RECENT HOUSEHOLD SURVEY

BICYCLE TYPE	STUDY SAMPLE (N=524)	HOUSEHOLD SURVEY[1] (N=3187)
LIGHTWEIGHT	51%	32%
STANDARD/MIDDLEWEIGHT	42%	52%
HIGHRISE	5%	12%
OTHER	2%	4%

[1]Diridon Research Corporation, 1973

sampling areas for this study, it is unlikely that the number of lightweight bicycles in use within the sampling areas would be greater than the lightweights in use within Santa Clara County, California, where the adult ridership is very high. For this reason, the data shown in Table 9 suggest that a disproportionate number of bicycle/motor-vehicle accidents involve lightweight bicycles. Although it is possible that accident rate would be constant across bicycle types if exposure (type, frequency, and amount of riding) was held constant, it is also possible that accident rate is higher for lightweight bicycles because the average speed is far greater than for other types of bicycles.

Motor-Vehicle Type

As was stated above, the type of motor vehicle involved in the accident was recorded on the official traffic accident report form in almost every case. Thus, data on motor-vehicle type were available for both the fatal and the non-fatal samples. The distributions of motor-vehicle type for the fatal and non-fatal samples are shown in Table 10. The parenthetical values adjacent to the name of the vehicle type represent the percentage of total vehicle registrations for the associated vehicle type (National Safety Council, 1976). For instance, 77.5% of all vehicles registered in the United States are passenger cars, 18.4% are trucks, and so on.

TABLE 10

TYPE OF MOTOR VEHICLE DRIVEN BY MOTORISTS IN THE FATAL AND NON-FATAL SAMPLES

VEHICLE TYPE	FATAL N	FATAL %	NON-FATAL N	NON-FATAL %
PASSENGER CAR (77.5%)[1]	126	*79.8*	658	*88.1*
TRUCK (18.4%)	30	*19.0*	70	*9.4*
Pickup or Van	24	*15.2*	61	*8.2*
Other Truck	6	*3.8*	9	*1.2*
MOTORCYCLE (3.7%)	1	*.6*	18	*2.4*
BUS (.4%)	1	*.6*	1	*.1*
TOTAL	158	*100*	747	*100*

[1]Parenthetical values show percent of total vehicle registrations for the associated vehicle type.

As would be expected, most of the motor vehicles involved in bicycle/motor-vehicle accidents are passenger cars. It can be seen that about 80% of the fatal accidents and 88% of the non-fatal accidents involved a passenger car (a significantly larger percentage of non-fatal than fatal accidents involved a passenger car [$p < .01$]). Comparison of the distribution for the study sample with the distribution of all registered motor vehicles shows that passenger cars are slightly overrepresented in the fatal sample and are overrepresented in the non-fatal sample by more than ten percent. Although the reasons for the overrepresentation of passenger cars in bicycle/motor-vehicle accidents is not known for certain, it is probable that the most important reason is that passenger cars are more often driven in the areas where bicycle density is greatest.

Table 10 shows that trucks are involved in a proportionately greater number of fatal accidents (19%) than non-fatal accidents (9.4%). More than 80% of the trucks were pickups or vans; the remainder were larger types of trucks. These data suggest that the likelihood of fatal injuries increases as a function of the size of the vehicle. For instance, dividing the proportion of fatal cases by the proportion of non-fatal cases yields a ratio of .9 for passenger cars, 1.9 for pickups and vans, and 3.2 for larger types of trucks. Because of the small number of cases involving a truck, these data can only be considered suggestive. Because all the required information is contained on traffic accident report forms, it would be a relatively simple matter to conduct a large and comprehensive survey to determine the likelihood of fatal injuries as a function of vehicle type.

Only one fatality resulted from a collision between a bicycle and a motorcycle (actually, both the bicyclist and the motorcyclist were killed in this accident). Motorcycles were involved in a proportionately greater number of non-fatal accidents (2.4%). Although motorcycles were involved in bicycle/motor-vehicle accidents less often than would be predicted from their numbers, it is possible that the accident rate per mile driven may be greater than for other types of motor vehicles.

The small number of bicycle/motor-vehicle accidents involving a bus was somewhat surprising. Considering the width of a bus and the type of areas in which they travel, it seems reasonable to expect a greater number of bicycle-bus accidents than was revealed by the sample. This result is probably a function of the skill of the bus drivers and a recognition by bicyclists that buses constitute a serious threat.

VEHICLE CONDITION

The bicyclists who were interviewed were asked to identify both the safety equipment and the vehicle defects for the bicycle they were riding at the time of the accident. To minimize the effects of recall, checklists were provided for safety equipment (Appendix B, p. B-104) and defects (Appendix B, p. B-105). The motorists who were interviewed were asked to identify equipment defects for the motor vehicle they were driving at the time the accident occurred. A checklist was also used to assess motor-vehicle defects (Appendix B, p. B-125).

Bicycle

Safety equipment. Bicyclists were asked to identify the safety equipment that was on the bicycle they were riding when the accident occurred and to indicate whether or not the items they checked were in good working order. The bars in Figure 13 indicate the proportions of bicycles in the non-fatal sample that were equipped with the associated safety item. The shaded portion of the bar indicates the proportion of cases in which the item was defective.

It can be seen that the vast majority of bicycles were not equipped with all the safety items that most experts consider essential for safe riding and, in some cases, that are required by law. Only four of the safety-equipment items were found on the majority of bicycles: handlebar grips

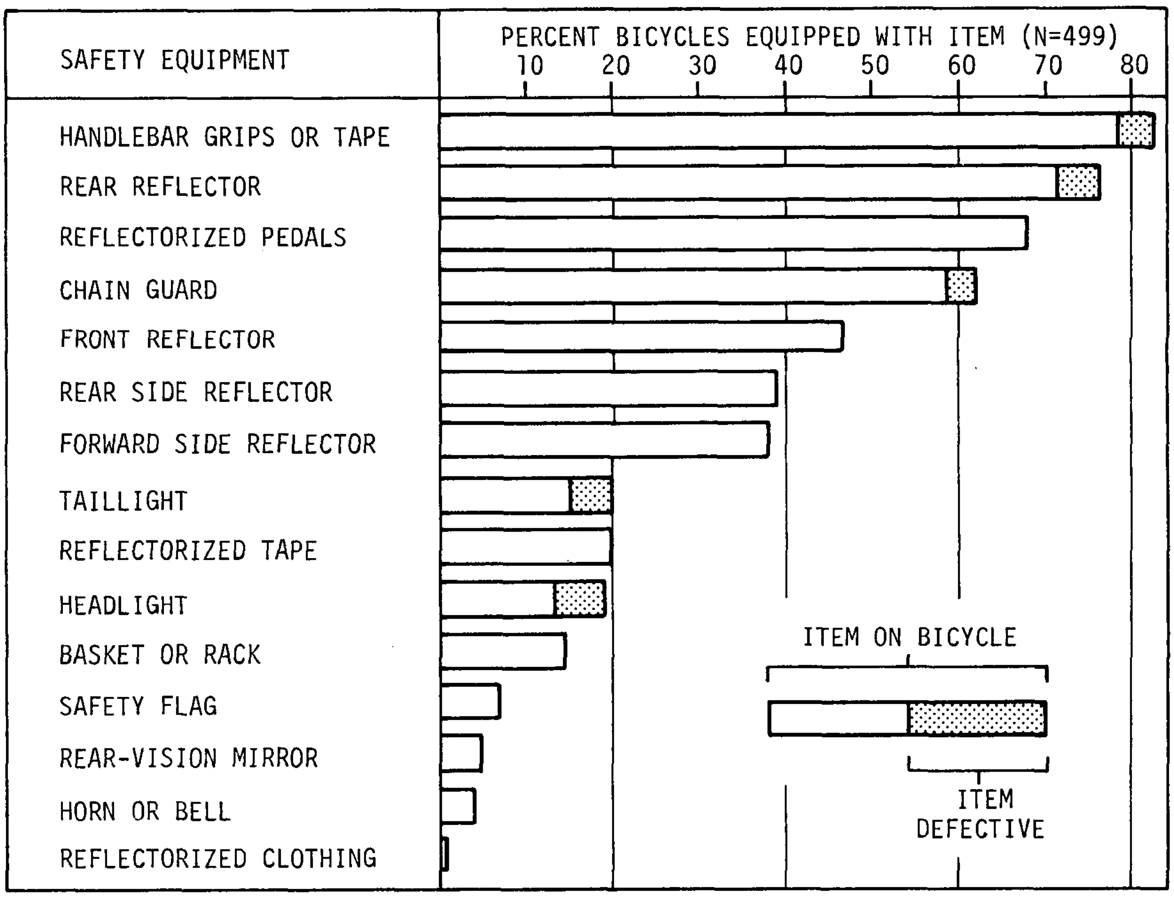

Figure 13. Safety equipment on the bicycles in the sample of non-fatal accidents.

or tape (83%), rear reflector (76%), reflectorized pedals (68%), and chain guard (62%). Although a front reflector and a forward and rear side reflector are required by law, it can be seen that only about 47% of the bicycles were equipped with a front reflector and about 38% were equipped with a forward and rear side reflector. Twenty percent or fewer of the bicycles were equipped with the remaining safety items. It is interesting to note that while about 20% of the bicycles were equipped with a taillight and headlight, about five percent of all taillights and headlights were defective or otherwise inoperable at the time the accident occurred. It is also of interest to note that only seven percent of the bicycles were equipped with a safety flag and that less than five percent were equipped with a rear-vision mirror (this percentage includes head-mounted rear-vision mirrors as well).

It might be argued that while many bicycles are not equipped with the necessary lighting equipment, such ill-equipped bicycles are not often ridden at night. For this reason, the availability of lighting equipment was tabulated separately for daytime and nighttime accidents. This tabulation is shown in Table 11. It can be seen that the proportion of bicycles equipped with the various lighting equipment was similar for the daytime and nighttime accidents. The proportions differed significantly only for reflectorized clothing where it was found that a significantly larger percentage of bicyclists involved in nighttime accidents were wearing reflectorized clothing ($p < .05$). However, the absolute number of bicyclists who were wearing reflectorized clothing at the time of the accident was so small that this finding has little significance.

These data would be most meaningful if it were possible to compare the safety equipment on bicycles in the accident sample with the safety equipment on the general population of bicycles in the sampling areas. Unfortunately, no data have been located that enable one to estimate the percentage of bicycles in the general population that are equipped with the safety items investigated in this study. However, based upon casual observations, the authors believe that bicycles in the accident sample would not differ significantly from those in the general population.

TABLE 11

LIGHTING EQUIPMENT ON BICYCLES INVOLVED IN DAYTIME AND NIGHTTIME ACCIDENTS (NON-FATAL ACCIDENT SAMPLE)

LIGHTING EQUIPMENT	PERCENT BICYCLES EQUIPPED WITH ITEM	
	DAYTIME ACCIDENTS (N=477)	NIGHTTIME ACCIDENTS (N=52)
REAR REFLECTOR	72.7%	67.3%
REFLECTORIZED PEDALS	73.1%	63.3%
FRONT REFLECTOR	44.4%	40.4%
REARWARD SIDE REFLECTOR	36.7%	38.5%
FORWARD SIDE REFLECTOR	35.4%	40.4%
TAILLIGHT	19.7%	21.1%
REFLECTORIZED TAPE	19.1%	15.4%
HEADLIGHT (OPERATIONAL)	19.1%	13.5%
REFLECTORIZED CLOTHING	.2%	1.9%

As is discussed in more detail later, lighting equipment and devices to increase the daytime conspicuity of the bicycle (safety flags, for example) are clearly the most crucial items of safety equipment. Other items are either present on most bicycles or, if absent, seldom contribute to bicycle/motor-vehicle accidents.

Defective equipment. During the interviews, the bicyclists were first asked to indicate on the checklist the equipment that was defective at the time of the accident, and then were asked to indicate whether the defect contributed to the accident in any way. The bars in Figure 14 indicate the proportion of bicyclists who reported the presence of the associated defect. The shaded portion of the bar indicates the proportion of cases in which the defect was present and judged contributory by the bicyclist.

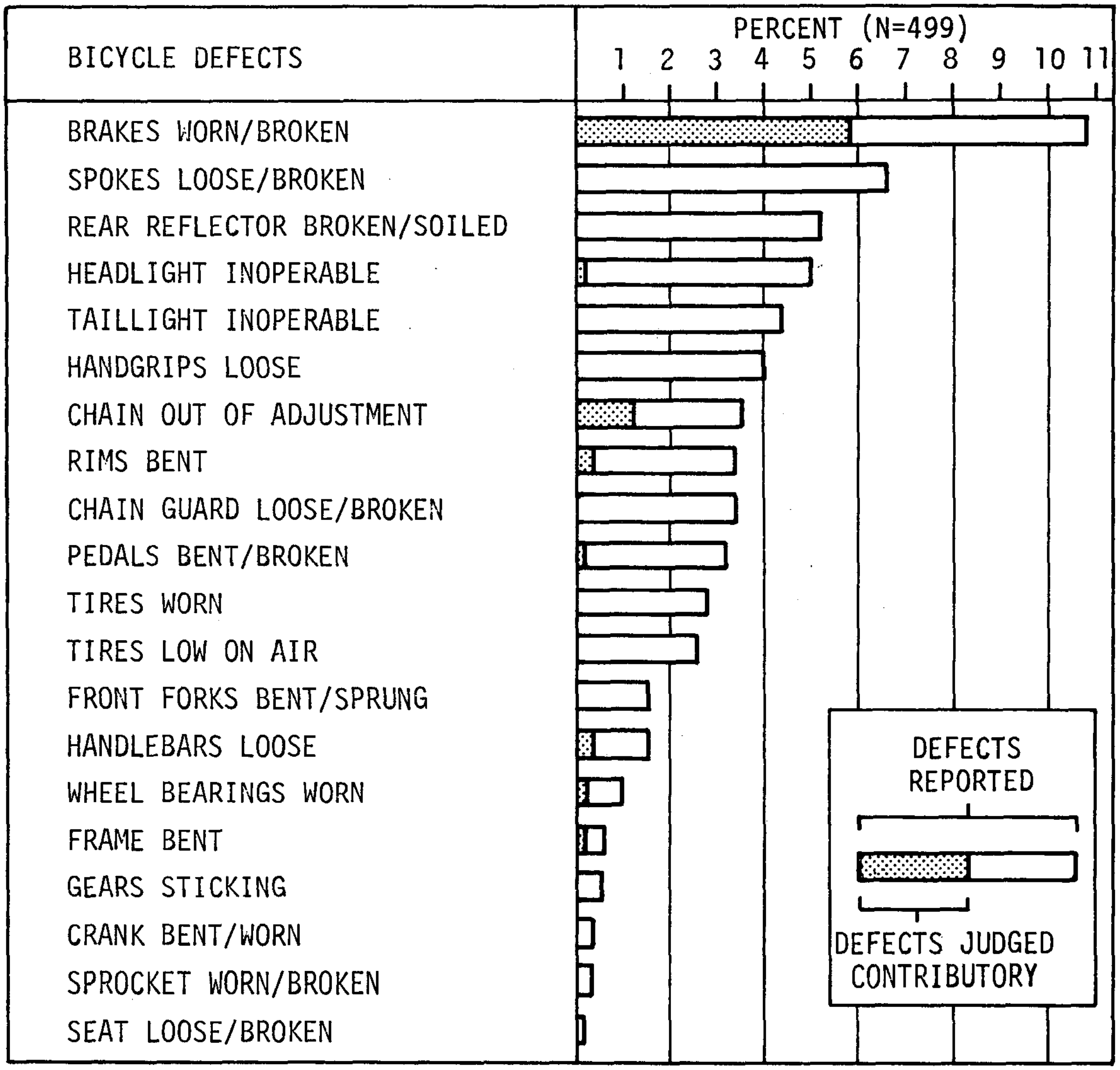

Figure 14. Bicycle defects reported and defects judged contributory by bicyclists in the non-fatal accident sample.

It can be seen that, although a significant proportion of the bicycles was defective, few of the defects were judged contributory by the operator. The one exception to this observation is defective brakes. Nearly 11% of the bicyclists reported that their brakes were defective at the time of the accident, and over half of them indicated that their defective brakes contributed to the accident. The authors' assessment of the contribution of bicycle defects did not always correspond with the judgment of the bicyclists. In a significant number of cases, it was found that the accident was imminent by the time the bicyclist first attempted to brake; so the defective brakes were judged non-contributory by the authors, even though the bicyclists believed that the brake defect did, in fact, contribute to the accident.

The main implication of these findings is that programs to eliminate bicycle defects, with the possible exception of defective brakes, cannot be expected to make a significant impact on the number of bicycle/motor-vehicle accidents that occur. This conclusion is supported by the findings of a study by the Virginia Department of Highways (1974) in which a bicycle defect was found to be a contributory factor in less than three percent of all bicycle/motor-vehicle accidents.

Motor Vehicle

Like the bicyclists, motorists who were interviewed were asked to indicate on a checklist the vehicle equipment that was defective at the time of the accident and to indicate whether they believed that the defect contributed to the accident. The vehicle defects reported and those judged contributory are shown in Figure 15, which is formatted in the same manner

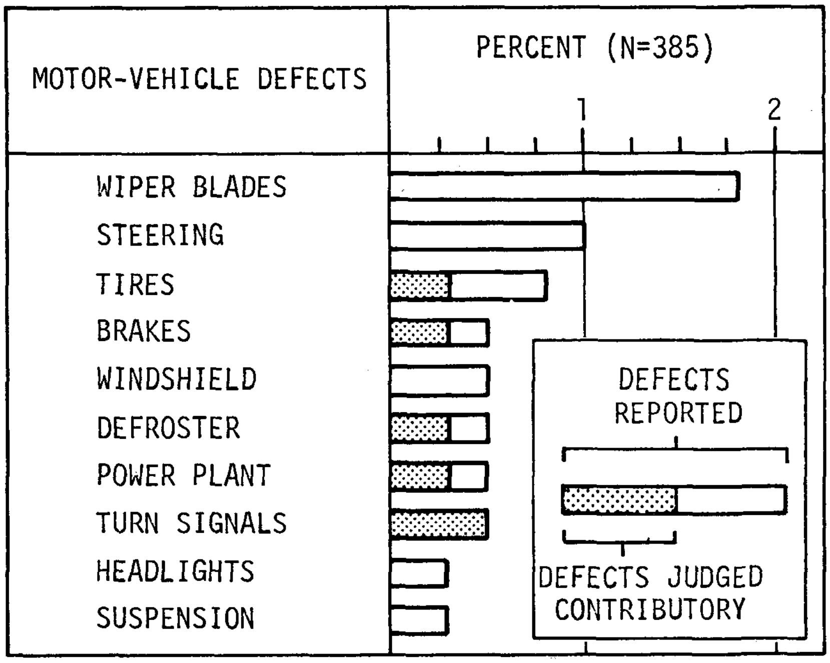

Figure 15. Motor-vehicle defects reported and defects judged contributory by motorists in the non-fatal accident sample.

as Figure 14. It is clear that defects were infrequent among the motor vehicles in the non-fatal sample and that contributory defects were even more infrequent. The defects reported most frequently (defective wiper blades and defective steering) were not judged contributory in a single case. The most frequent contributory defect was turn signals. It can be seen that every motorist who reported that their turn signals were defective also indicated that the defect contributed to the accident. The remaining defects were judged contributory by less than .3% of the motorists, if the defect was judged contributory at all. The authors' judgment of the contribution of vehicle defects corresponded closely with the judgments of the motorists, so it is clear that motor-vehicle defects are seldom a factor in bicycle/motor-vehicle accidents.

The results of this study correspond closely with the findings of Waller and Reinfurt (1969) who found that about one percent of the bicycle/motor-vehicle accidents involve a defective motor vehicle.

VEHICLE OWNER

It was reported earlier that most of the operators had driven the accident vehicle many times before the accident occurred and were thoroughly familiar with its operation. That finding is supported by the finding that the vast majority of the operators owned the vehicle they were driving at the time the accident occurred. Figure 16 shows that over 80% of the

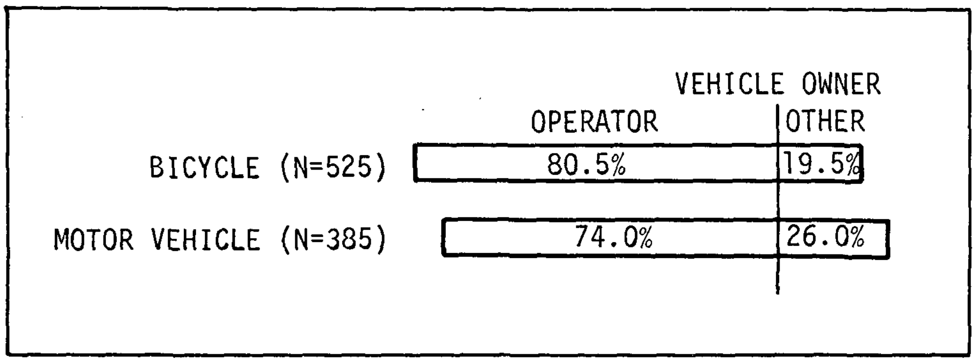

Figure 16. Proportions of operators who owned the vehicles being ridden/driven at the time of the accident (non-fatal accident sample).

bicyclists and 74% of the motorists were driving their own vehicle at the time the accident occurred.

Waller (1970) found that 37% of the injuries resulting from all types of bicycle-related accidents occurred to individuals who were not riding their own bicycle. However, since most of the accidents in his sample were *not* bicycle/motor-vehicle accidents, his findings are not directly comparable to the percentages reported in this study.

THE ACCIDENT TRIP

Described below are the characteristics of the trip the operators were on when the accident occurred. The trip characteristics discussed include: trip purpose, trip length, day of week, hour of day, and month of year.

TRIP PURPOSE

Bicyclist Trip Purpose

The distribution of trip purposes for the bicyclists in the non-fatal sample is shown in Table 12. An examination of the values in column 2 (PERCENT ACCIDENT SAMPLE) show that about 80% of the bicyclists were on a utilitarian trip to a specific destination, and about 20% of the bicyclists were on some type of recreational trip with no particular destination when the accident occurred. For bicyclists who were engaged in a utilitarian trip, the most common trip purposes were shopping or errands (21.7%), commuting to a place of recreation (20.5%), or visiting friends (18.6%). A smaller, but nevertheless significant, proportion of the bicyclists was commuting to school (10.7%) or commuting to work (8.4%).

About 18% of the bicyclists were on a recreational trip with no destination when the accident occurred--about 10% were simply riding around the neighborhood, and the remaining eight percent were engaged in some type of game or race with another person.

TABLE 12

DISTRIBUTION OF TRIP PURPOSES FOR BICYCLISTS IN THE NON-FATAL ACCIDENT SAMPLE COMPARED WITH ESTIMATES OF BICYCLING FREQUENCY BY TRIP PURPOSE

BICYCLIST'S TRIP PURPOSE	PERCENT ACCIDENT SAMPLE (N=525)		PERCENT OF ALL BICYCLING DAYS[2] TENNESSEE[1] (N=3141)	PERCENT OF ALL BICYCLING DAYS[2] PENNSYLVANIA[1] (N=6372)
UTILITARIAN (SPECIFIC DESTINATION)		79.9%	36.9%	49.7%
SHOPPING/ERRANDS	*21.7%*		*4.7%*	*9.1%*
COMMUTING TO PLACE OF RECREATION	*20.5%*		*10.8%*	*14.1%*
VISITING FRIENDS	*18.6%*		*17.2%*	*20.5%*
COMMUTING TO SCHOOL	*10.7%*		*2.9%*	*2.9%*
COMMUTING TO WORK	*8.4%*		*1.3%*	*3.1%*
RECREATIONAL (NO DESTINATION)		18.1%	63.1%	50.3%
NEIGHBORHOOD RIDING	*10.1%*			
GAME PLAYING	*8.0%*			
OTHER RECREATIONAL		1.8%		
ORGANIZED RACE/RIDE	*1.0%*			
TOURING	*.8%*			
DON'T REMEMBER		.2%		

[1]Data from household surveys completed by Barton-Aschman Associates for the Tennessee Departments of Conservation and Transportation (1974) and the Pennsylvania Department of Transportation (1975).

[2]A "bicycling day" is defined as a bicyclist participating in a particular bicycling activity on any given calendar day (several "bicycling days" could occur on one calendar day for a single bicyclist).

Only one percent of the bicyclists was engaged in an organized (sanctioned) race or ride, and only .8% was engaged in long-distance touring (a bicycling trip exceeding two hours in duration).

There are at least two reasons why accident likelihood may vary as a function of trip purpose. First, some types of trips may require bicyclists to ride in more hazardous locations and during more dangerous periods than others. For example, commuting to work usually requires the bicyclist to ride on busy streets during peak-hour traffic periods, while busy streets and peak-hour traffic can usually be avoided when the purpose of the trip is purely recreational. Secondly, there are some types of trips that involve more severe time constraints than others. The time constraints may, in turn, lead the bicyclist to take more chances in traffic than under ordinary circumstances.

In an attempt to determine if accident likelihood varies as a function of trip purpose, the literature was searched for data on the relative proportions of all bicycling trips that are made for different purposes. Two survey studies were located that provided estimates of the relative proportion of all "bicycling days" on which at least one trip for a given purpose was made. These data were compiled during statewide household surveys in the State of Tennessee (Barton-Aschman, 1974) and the State of Pennsylvania (Barton-Aschman, 1975). In these surveys, a "bicycling day" was defined as a bicyclist participating in a particular bicycling activity on any given calendar day. The comparison of the survey data with the accident data is complicated by the fact that several "bicycling days" could occur on one calendar day for a single bicyclist. That is, if a bicyclist made three separate trips to visit friends and one trip to school, the data would show one bicycling day for visiting friends and one bicycling day commuting to school. Assessing the relationship between accident likelihood and trip purpose from these data is also complicated by the fact that trips for different purposes may vary in their length and, therefore, the relative exposure of the bicyclist. For these reasons, caution must be exercised when comparing the accident data and the household survey data shown in Table 12.

Table 12 shows that about 37% of the bicycling days in Tennessee and about 50% of the bicycling days in Pennsylvania involved at least one utilitarian trip, yet about 80% of the bicyclists in the study sample (non-fatal) were on a utilitarian trip when their accident occurred. Despite the confounding factors discussed above, these data suggest that accident likelihood may be substantially greater on utilitarian trips than on non-utilitarian trips. The findings are consistent with the hypothesis that accident likelihood is, in fact, higher for utilitarian trips, and that the difference is because more utilitarian trips than non-utilitarian trips must be made during periods of high traffic density and involve travel in commercial areas where both traffic speed and traffic congestion tend to be highest. For all but one type of utilitarian trip, the percentage values for the accident sample are significantly greater than the corresponding percentage values for both the Tennessee and the Pennsylvania household surveys. Accidents while on a trip to visit friends occur in direct proportion to the number of such trips that are made. It seems reasonable to assume that most trips to visit friends are made in residential areas and are no more likely (and perhaps less likely) during periods of peak-hour traffic than during other periods. Conversely, shopping trips and commuting trips to school or work occur far more frequently during peak-hour traffic and are far more likely to take the bicyclist into an area where traffic volume and speed are high.

The relationship between accident likelihood and trip purpose that is suggested by these data is sufficiently important to warrant verification by further research. If valid, this relationship suggests that the current attempts to promote greater utilitarian use of bicycles may result in a disproportionately large increase in bicycle/motor-vehicle accidents if special remedial action is not taken.

Motorist Trip Purpose

Table 13 shows the distribution of trip purposes for motorists in the non-fatal sample. As was true for bicyclists, the overwhelming majority of motorists were engaged in a utilitarian trip when the accident occurred. It can be seen that only 3.1% were on a recreational trip with no specific destination and that the remaining 96.4% were on a utilitarian trip with a specific destination.

It would be of interest to compare the distribution of trip purposes for the accident sample with the distribution of trip purposes for the general motoring population. Unfortunately, such a comparison is impossible because a) most origin-destination studies are limited either to to inter-city or intra-city travel and b) the trip-purpose categories that traditionally have been used in origin-destination studies are different from those used in this study. Even so, it is interesting to note that

TABLE 13

DISTRIBUTION OF TRIP PURPOSES FOR MOTORISTS IN THE NON-FATAL ACCIDENT SAMPLE

MOTORIST'S TRIP PURPOSE	PERCENT MOTORISTS INTERVIEWED (N=385)	
UTILITARIAN (SPECIFIC DESTINATION)		96.4%
SHOPPING/ERRANDS	*41.1%*	
COMMUTING TO WORK	*23.4%*	
VISITING FRIENDS/RELATIVES	*14.0%*	
COMMUTING TO PLACE OF RECREATION	*12.7%*	
COMMUTING TO SCHOOL	*5.2%*	
RECREATIONAL (NO DESTINATION)		3.1%
LOCAL DRIVING	*2.6%*	
NON-LOCAL DRIVING	*.5%*	
DON'T REMEMBER		.5%

Tittemore and his colleagues (1972), in a comprehensive study of local travel in eight different cities, showed about the same proportion of commuting trips to work and school (29%) as was found for motorists in the study sample (28.6%).

TRIP LENGTH

Table 14 shows the centiles of the one-way trip length distributions for the bicyclists and motorists in the non-fatal accident sample. It can be seen that most bicyclists were on a relatively short trip when the accident occurred. Half the bicyclists were on a trip of 1.1 miles or less and one-fourth were on a trip of .4 mile or less. While some of the bicyclists were on trips as long as 30 miles, Table 14 shows that only five percent of the bicyclists were on a trip whose length exceeded 3.4 miles.

As would be expected, motorists' trips, on the average, were longer than those of the bicyclists. However, there were surprisingly few motorists who were on exceedingly long trips. The main implication of these

TABLE 14

DISTRIBUTION OF TRIP LENGTH (ONE-WAY) FOR BICYCLISTS AND MOTORISTS IN THE NON-FATAL ACCIDENT SAMPLE

	CENTILES (MILES)				
	5TH	25TH	MEDIAN 50TH	75TH	95TH
BICYCLISTS (N=525)	.1	.4	1.1	2.1	3.4
MOTORISTS (N=385)	.5	2.6	5.8	10.2	29.4

data is that few of the operators--bicyclists and motorists--were on a trip that was so long that it would require them to travel in altogether unfamiliar territory or that would be extremely physically fatiguing.

DAY OF WEEK

Figure 17 shows the distribution of accidents in the study sample by day of week (hereafter referred to as "daily distribution"). The arrow on the scale at the top of Figure 17 shows the daily percentage value (14.2%) that would have been obtained if accidents occurred with equal frequency throughout the week. It is clear from even a cursory examination of this figure that the accidents in the study sample do *not* exhibit the same daily distribution as is traditionally found for motor-vehicle accidents.[11] Motor-vehicle accidents characteristically occur with about the same frequency from Monday through Thursday (11%-12%) and show a sharp increase on Friday, Saturday, and Sunday (16%-21%). In contrast, the daily distribution of bicycle/motor-vehicle accidents in the study sample fails to show an increase on the weekend. In fact, the non-fatal cases occur significantly less often ($p < .01$) on Saturday and Sunday than on the remaining days of

[11]The National Safety Council (1976) reports the following distribution of motor-vehicle deaths by day of week: Monday, 11%; Tuesday, 12%; Wednesday, 11%; Thursday, 12%; Friday, 17%; Saturday, 21%; and Sunday, 16%.

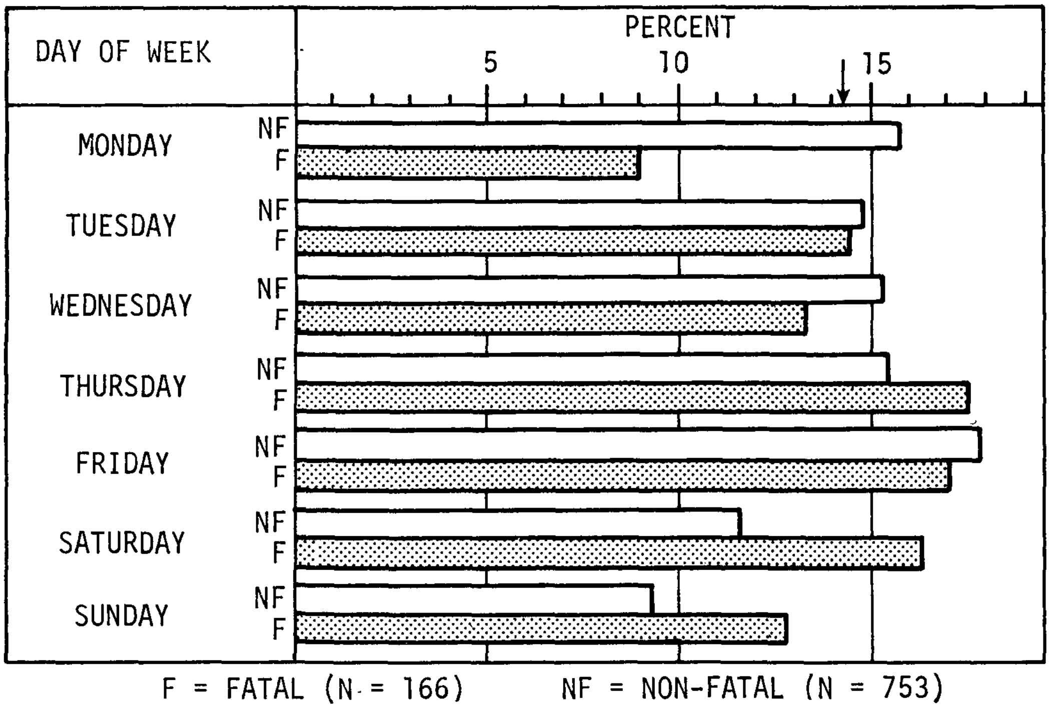

Figure 17. Distribution of accidents by day of week.

the week. The percentage values for fatal and non-fatal cases differ significantly (p <.05) for Monday (significantly fewer fatal than non-fatal cases), but the differences are not statistically significant for the remaining days of the week.

In Figure 18, the daily distribution of accidents in the study sample is compared with the daily distributions reported in other recent studies of bicycle/motor-vehicle accidents, including:

- Virginia Department of Highways, 1973 (2,955 accidents),
- Waller and Reinfurt, 1969 (2,453 accidents),
- Washington State Patrol, 1972 (1,012 accidents), and
- Williams, 1974 (888 accidents).

The daily distribution of the non-fatal cases in the study sample is indicated by the circles; the horizontal lines indicate the range of percentage values reported in the four studies referenced above. Since nearly all the cases in the referenced studies were non-fatal accidents, it is appropriate to compare them only with the non-fatal cases in the study sample.

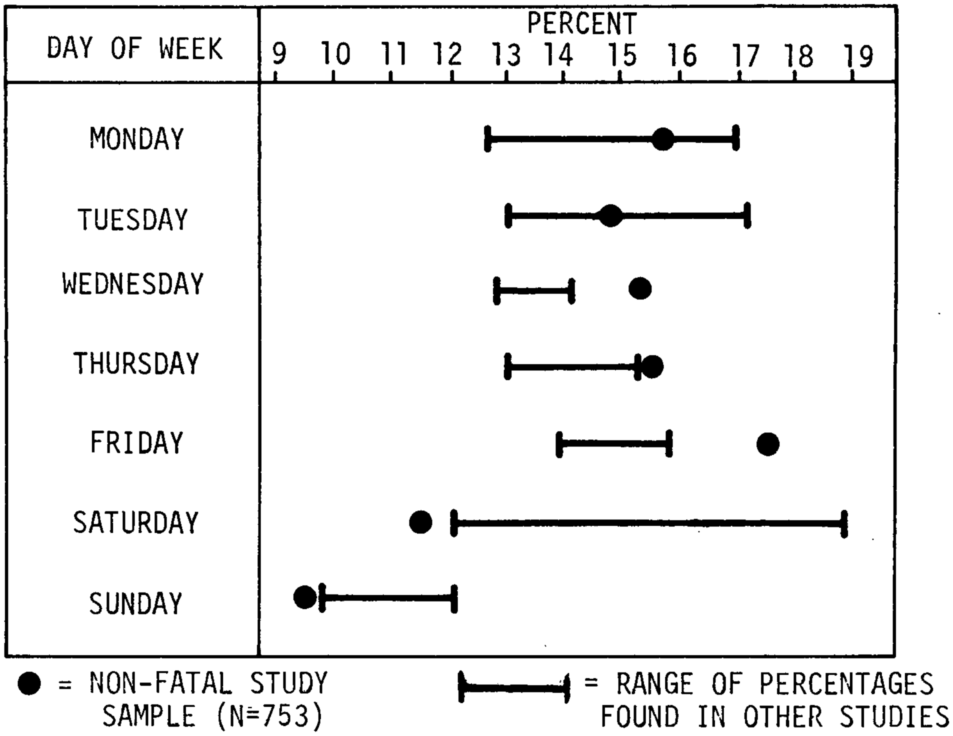

Figure 18. Distribution of non-fatal accidents by day of week for the study sample compared with the distributions for other studies of bicycle/motor-vehicle accidents.

It can be seen that on five of the seven days, the percentages obtained for the study sample fall outside the range of values reported in the other four accident studies. However, the differences are small in comparison to the total range of values found for the other four accident studies. On all five days, the percentage values for the study sample are within two percentage points of the range. In short, the daily distribution obtained for the study sample can be considered reasonably representative.

It is clear from these data that bicycle accidents represent a serious problem on every day of the week. Although accidents consistently occur less often on Sunday than any other day, Sunday accidents account for between nine percent and 12% of the total. Conversely, there is no day of the week that clearly is more important than any other day. Although all the studies reported a clear peak on a single day (Friday or Saturday), the magnitude of the peak is not great enough to warrant tailoring countermeasures to a single day of the week.

TIME OF DAY

Figure 19 shows the distributions of fatal and non-fatal accidents in the study sample by time of day. Also shown (solid circles) is the distribution of all motor-vehicle accidents by time of day (National Safety Council, 1976). It can be seen that the distribution of bicycle/motor-vehicle accidents is similar but somewhat more pronounced than the

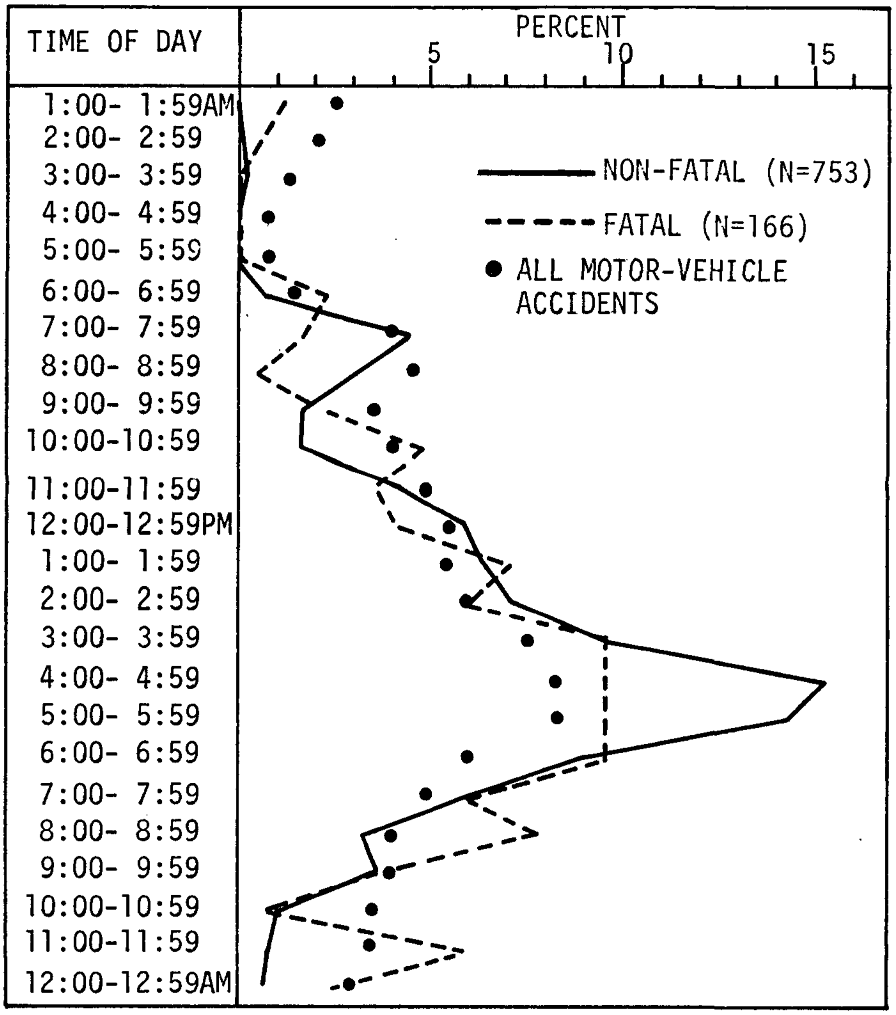

Figure 19. Distributions of fatal and non-fatal accidents by time of day.

distribution of all motor-vehicle accidents. That is, there is a minor peak during the morning rush hours between 7:00 and 9:00 AM and a major peak during the evening rush hours between 3:00 and 7:00 PM.

The distributions of fatal and non-fatal accidents differ in two important respects. First, a relatively smaller proportion of fatal than non-fatal accidents occur during the evening rush hours. While the absolute number of fatal accidents is greatest during these hours, the likelihood of a fatal accident apparently does not increase as a simple function of exposure. Secondly, the relative proportion of fatal accidents occurring after 8:00 PM is greater than the proportion of non-fatal accidents that occur after this time. The relatively higher incidence of fatal accidents after 8:00 PM is almost surely due to darkness. As will be shown later, the types of accidents that occur during darkness are more likely to result in fatal injuries to the bicyclist.

Nearly identical distributions of accidents as a function of time of day are reported by Waller and Reinfurt (1969), Walsh and Watt (1974), and the Washington State Patrol (1972). All three of these studies show a secondary peak during the morning rush hours and a major peak during the evening rush hours. Furthermore, the reported percentage values are nearly identical to one another and to the percentage values for the non-fatal accidents presented in this study.

Because the time of sunrise and sunset varies as a function of time of year and geographical location, it is not possible to determine the number of accidents that occur during darkness from knowing only the time of day at which the accident occurred. Thus, the Field Investigators were asked to determine the ambient lighting conditions at the time of the accident. Table 15 shows the proportions of fatal and non-fatal accidents that occurred during daylight, darkness, dusk, and dawn. Since most bicycling is done during daytime, it comes as no surprise that most accidents occur during daylight hours. More important is the finding that the proportion of fatal accidents occurring during darkness is significantly greater than the proportion of non-fatal accidents occurring during

TABLE 15

LIGHT CONDITIONS AT THE TIME OF THE ACCIDENT

LIGHT CONDITION	FATAL (N=166)	NON-FATAL (N=753)
DAYLIGHT	64.5%	85.2%
DARKNESS	30.1%	10.2%
DUSK	3.6%	3.8%
DAWN	1.8%	.8%

darkness ($p < .01$). The proportions of accidents occurring during dusk and dawn do not differ significantly for the fatal and non-fatal samples.

The proportion of non-fatal cases that occurred during darkness in this study is remarkably similar to the proportions found in other studies of bicycle/motor-vehicle accidents. For instance, in seven recent studies of bicycle/motor-vehicle accidents, the proportion of nighttime accidents varied only from five to 14% (Vilardo & Anderson, 1969; Waller & Reinfurt, 1969; Brezina & Kramer, 1970; Washington State Patrol, 1972; Popish & Lytel, 1973; Walsh & Watt, 1974; Williams, 1974). The above studies contained so few fatal accidents that no attempt was made to estimate the proportion of fatal accidents that occurred during darkness. However, since the number of fatal cases in the study sample comprise nearly 17% of all fatal accidents that occurred in the United States during the sampling period, one can be confident that the finding that 30% of all fatal accidents occur during darkness is a reasonably reliable estimate. For the non-fatal accidents that occurred during darkness, 35% occurred in an area that was not illuminated by street lights. In contrast, 64% of the fatal accidents that occurred during darkness were at a location that was not illuminated by street lights.

MONTH OF YEAR

It will be recalled that accident cases were drawn from each month during calendar year 1975 in direct proportion to the number of accidents that occurred in the corresponding month of 1974. Therefore, the proportion of accidents in the study sample of non-fatal cases that occurred during each month is an accurate reflection of the distribution of accidents by month of year throughout the sampling areas. The distribution of accidents by month of year for the study sample is shown in Figure 20. Also shown is the range of values reported in four independent studies of bicycle/motor-vehicle accidents (Vilardo & Anderson, 1969; Waller & Reinfurt, 1969; Washington State Patrol, 1972; and California Highway Patrol, 1974).

It can be seen that all studies showed the same characteristic trend. Accident frequency is substantially higher during the summer months, somewhat less during late spring and early fall, and lowest during the late fall and winter (November through March). The seasonal trend is due to two factors: a) young bicyclists ride more during the summer months when school is out, and b) nearly all bicyclists ride less during the months when the temperature is low and precipitation is frequent.

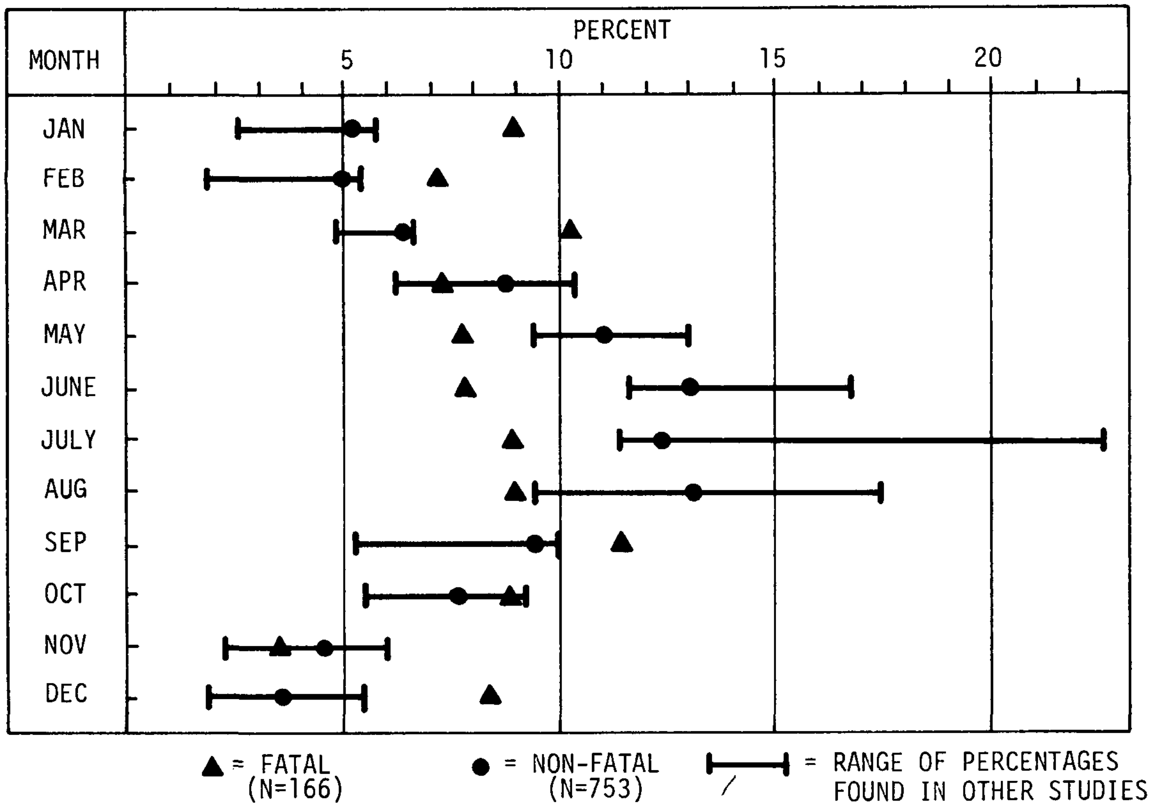

Figure 20. Distribution of accidents by month of year for the study sample compared with the distribution for other studies of bicycle/motor-vehicle accidents.

The seasonal trend in the study sample is not so marked as for other studies. That is, the difference in the proportions of accidents during the summer and winter months is not as great as is reported in other studies. This finding is because two of the sampling areas were located in areas where the temperature is relatively moderate throughout the year (California and Florida). However, the same general trend was found in both of these states. Since most of the cases in the fatal sample were drawn from either California or Florida, it is not surprising that the seasonal trend does not appear in the distribution of fatal accidents. That is, in California and Florida, fatal accidents occur with about the same frequency for each month throughout the year.

Because the distribution of non-fatal cases falls well within the range reported in other studies, it seems reasonable to assume that the non-fatal sample is representative in terms of the monthly distribution. The fatal sample, however, is probably representative only of states where bicycles can be ridden comfortably throughout the year.

WEATHER CONDITIONS

Most of the accident trips were made during conditions of fair weather. A small, but significant, number of accidents occurred when rain was falling (3.1% of the non-fatal cases and six percent of the fatal cases). Only one or two cases in the entire sample occurred when it was snowing, during a period of heavy fog, or in an area with blowing sand or dust. Consequently, except for the small number of cases that occurred when it was raining, there were few cases in which adverse weather conditions were present and could have contributed to the accident.

THE ACCIDENT LOCATION

The accident location is described below in terms of the urban-rural designation of the area, the predominant use of the land in the vicinity of the accident site, and the characteristics of the roadway the operators were traveling just prior to the accident.

URBAN-RURAL DESIGNATION

Traditionally, the location of all types of traffic accidents is designated as urban or rural by the investigating officer or by another representative of the law enforcement agency. Law enforcement agencies most commonly differentiate urban and rural areas in terms of either the incorporation status of the area or the number of inhabitants who reside within a built-up area. As a consequence, urban accidents may be defined as those which occur within the political boundary of an incorporated area or those which occur within communities inhabited by more than some prescribed number of persons (sometimes 2,500 or more and sometimes 5,000 or more). Rural accidents are those that are not designated as urban.

Clearly, it is not possible to draw valid inferences about the characteristics of an area knowing only that it was designated urban or rural by a representative of an enforcement agency. During a preliminary examination of the accidents in the study sample, it was noted that many of the accidents that were officially designated as rural, in fact, occurred in densely populated residential communities located in the unincorporated fringe of a large population center. Although such areas were unincorporated and therefore officially rural, the characteristics of the areas were urban in every important respect. A smaller, but significant, number of cases were noted in which accidents officially designated as urban occurred in areas that were truly rural in character. Therefore, with the classification criteria that are used by law enforcement agencies, it is altogether possible that an accident designated as rural may have occurred in an area that is truly urban in character, and vice versa.

It is for this reason that all the accidents in the study sample were reclassified using more meaningful classification criteria. For purposes of defining accident causation, the most important differences between urban and rural areas are the posted speed limit and the motorists' expectations about encountering bicyclists in the area. Other differences that *may* be important include the presence of sidewalks, the presence of street lighting, roadway surface type, and the type and surface condition of the roadway shoulder. For the non-fatal sample, accidents were usually classified as rural if they occurred in an area where a) the posted speed limit was 45 miles per hour or more; b) there were no curbs or sidewalks adjacent to the roadway; c) street lights were not present at intersections; and d) at least 50% of the area within one-half mile radius of the accident site was open. A deviation from these classification criteria was necessary in only a few instances. For example, a few cases occurred in rural recreational areas with a posted speed limit below 45 miles per hour; these cases were classified as rural. Although the same general criteria were used to classify cases in the fatal sample, information about land use in the area was available only for the cases that occurred within the sampling areas and were investigated by the Field Investigator. Consequently, the classification of fatal cases was changed from the official classification only if information on the official traffic accident report form or the Field Investigator's site inspection indicated that the official designation was invalid in terms of the classification criteria described above.

The designation of accident location is shown in Figure 21 for the fatal sample, the non-fatal sample, and the combined sample. The term "incorporated" refers to the cases that were *officially* designated as urban accidents; the term "unincorporated" refers to the cases that were *officially* designated as rural accidents; and the term "rural" refers to the cases classified as rural by the project staff. The shaded bar is positioned to show the correspondence between the official designation of accident location and the designation made by the project staff.

Figure 21 shows that a portion of the accidents classified as rural by the project staff occurred within an incoporated area and were officially designated as urban (see the part of the bar labeled "incorporated" that is shaded). Similarly, it can be seen that a portion of the accidents classified as urban by the project staff occurred within an unincorporated area and were officially classified as rural (see the part of the bar entitled "unincorporated" that is not shaded).

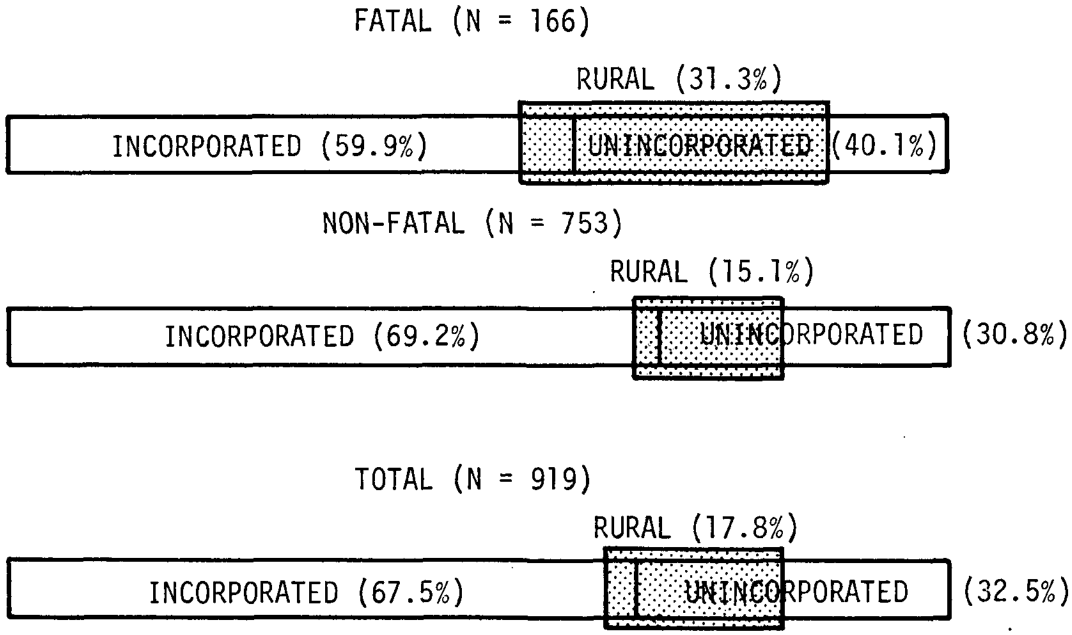

Figure 21. Classification of accident site by incorporated versus unincorporated and by urban versus rural designation.

An examination of the data for the combined samples shows that slightly over two-thirds of the cases occurred in an incorporated area and that the remaining cases occurred in an unincorporated area. About 18% of the cases in the combined samples were classified as rural by the project staff. Of the cases classified as rural, about 17% occurred in an incorporated area, and about 83% occurred in an unincorporated area. Stated differently, it was found that 95% of the accidents that occurred in an incorporated area were classified as urban by the project staff, but only 47% of the accidents that occurred in an unincorporated area were classified as rural by the project staff.

A comparison of the distributions for the fatal and non-fatal samples revealed that:

- The proportion of cases that occurred in an unincorporated area is significantly greater for the fatal sample than the non-fatal sample ($p < .05$).
- The proportion of cases classified by the project staff as rural is significantly greater for the fatal sample than the non-fatal sample ($p < .01$).

For comparison purposes, the distributions of urban and rural accidents (official designation) reported in other studies of bicycle/motor-vehicle accidents are shown in Table 16. (When examining the values in Table 16, keep in mind that the terms urban and rural, as used in the table, refer to the designations assigned by a representative of a law enforcement agency.) The main reason for presenting the data in Table 16 is to illustrate the wide range of values reported from one area to another. For instance, it can be seen that the values for fatal rural accidents vary from 40% to nearly 90%. Similarly, the values for non-fatal rural accidents vary from 20% to 39.3%. The reasons for these large differences are not known, but it is reasonable to assume that they are partly due to differences in the definition of rural accidents and partly due to the amount of bicycling that is done in truly rural areas.

At the present time, neither this study nor other studies reported in the literature provide the information needed to formulate a highly reliable estimate of the proportion of bicycle/motor-vehicle accidents that occur in areas that are truly urban or truly rural. However, a tentative estimate can be made using the following estimates of the proportions of cases in which the official designation is correct:

TABLE 16

DISTRIBUTION OF URBAN AND RURAL ACCIDENTS REPORTED IN OTHER STUDIES OF BICYCLE/MOTOR-VEHICLE ACCIDENTS

DATA SOURCE	SAMPLE PERIOD	SAMPLE SIZE	PERCENT FATAL		PERCENT NON-FATAL	
			URBAN	RURAL	URBAN	RURAL
NATIONAL SAFETY COUNCIL (1974) (NATIONWIDE SAMPLE)	CY 1973	*F= 1,150 NF=40,000	60.0%	40.0%	80.0%	20.0%
VIRGINIA DEPARTMENT OF HIGHWAYS (1974)	CY 1969- CY 1972	F= 44 NF= 2,911	33.3%	66.7%	60.7%	39.3%
WALLER AND REINFURT (1969) (STATE OF NORTH CAROLINA)	JULY 1965- JUNE 1968	F= 108 NF= 2,345	11.1%	88.9%	60.9%	39.1%
WASHINGTON STATE PATROL (1973)	CY 1968- CY 1972	F= 61 NF= 3,518	41.0%	59.0%	64.7%	35.3%

*F = FATAL; NF = NON-FATAL

- 90.9% of the fatal accidents in incorporated areas are correctly classified as urban.
- 67.2% of the fatal accidents in unincorporated areas are correctly classified as rural.
- 96.2% of the non-fatal accidents in incorporated areas are correctly classified as urban.
- 41.4% of the non-fatal accidents in unincorporated areas are correctly classified as rural.

According to the National Safety Council (1974), a) 60% of the fatal accidents occur in incorporated areas, and 40% occur in unincorporated areas; b) 80% of the non-fatal accidents occur in incorporated areas, and 20% occur in unincorporated areas. Applying the estimates of the proportions of cases correctly classified to the National Safety Council's estimates of the distribution of incorporated and unincorporated accidents yields the following estimates:

	FATAL	NON-FATAL
URBAN	68%	89%
RURAL	32%	11%

It is believed that the above estimates are the best available. However, additional research should be conducted to verify these estimates.

LAND USE IN ACCIDENT AREA

The accident location can be characterized in terms of the land use in the vicinity of the accident site. Table 17 is a matrix showing the predominant land use in the general area (within one-half mile radius of the accident site) and the proximal area (within 300 feet radius of the accident site). These data are for the non-fatal sample only. The marginal totals for rows show the proportions for the general area, and the marginal totals for columns show the proportions for the proximal area. The cells along the diagonal of the matrix show the proportions of cases in which the predominant land use in the general area was the same as for the proximal area. The remaining cells show the proportions of cases in which the predominant land use in the general area differed from the predominant land use in the proximal area.

TABLE 17

PREDOMINANT LAND USE IN THE GENERAL AREA (ONE-HALF MILE RADIUS OF ACCIDENT SITE) AND THE PROXIMAL AREA (300 FEET RADIUS OF ACCIDENT SITE) FOR THE NON-FATAL ACCIDENT SAMPLE

		PROXIMAL AREA (300 FEET RADIUS)								
		LOW-INCOME RESIDENTIAL	MIDDLE-INCOME RESIDENTIAL	UPPER-INCOME RESIDENTIAL	BUSINESS/ COMMERCIAL	INDUSTRIAL	RECREATION	SCHOOL	AGRICULTURAL/ OTHER OPEN	TOTAL
GENERAL AREA (ONE-HALF MILE RADIUS)	LOW-INCOME RESIDENTIAL	10.9%	.5%	---	2.8%	---	---	.3%	1.6%	16.1%
	MIDDLE-INCOME RESIDENTIAL	.7%	28.9%	.1%	6.7%	---	.3%	.1%	1.9%	38.7%
	UPPER-INCOME RESIDENTIAL	.1%	---	3.8%	.1%	---	---	---	.4%	4.4%
	BUSINESS/ COMMERCIAL	.4%	.7%	---	19.4%	---	.1%	.1%	1.2%	21.9%
	INDUSTRIAL	---	---	---	.1%	.7%	---	---	.1%	.9%
	RECREATION	---	.1%	.1%	.4%	---	1.5%	---	.3%	2.4%
	SCHOOL	.1%	---	---	---	---	---	.7%	.1%	.9%
	AGRICULTURAL/ OTHER OPEN	.6%	1.1%	.1%	.8%	.1%	.3%	.3%	11.4%	14.7%
	TOTAL	12.8%	31.3%	4.1%	30.3%	.8%	2.2%	1.5%	17.0%	100%

An examination of the marginal totals for rows shows that nearly 60% of the accidents occurred in a general area that was predominantly residential--mostly middle-income residential. Nearly 22% of the cases occurred in a general area that was predominantly business or commercial; and nearly 15% of the cases occurred in a general area that was predominantly agricultural or other open (excluding recreational which accounted for 2.4% of the cases). Less than one percent of the cases occurred in areas that were predominantly industrial or school.

The predominant land use in the general and proximal areas was the same in more than 77% of the cases. Examining the cases in which the land use in the general and proximal areas were different, it can be seen that more than nine percent of the cases occurred in close proximity to a business or commercial site that was located in a predominantly residential area. Nearly four percent of the cases occurred in close proximity to an open area that was located within a predominantly residential area.

It is clear from these data that most of the bicycle/motor-vehicle accidents occurred within a residential area. A substantially smaller, but nevertheless significant, proportion of cases occurred in business/commercial areas and agricultural/other open areas. It is important to note that a relatively small proportion of the accidents occurred in close proximity to a school area. This finding is surprising in view of the fact that the volume of bicycle traffic in close proximity to a school is certain to be far higher than for any other type of area. Apparently, one or both operators exercise more caution in school areas than other types of areas.

PROXIMITY TO OPERATOR'S RESIDENCE

Data were presented earlier showing that about 62% of the bicyclists and 84% of the motorists had driven through the accident site at least 50 times before the accident occurred (see Table 6). Reference to Table 18 shows that the operator's high degree of familiarity with the accident site was mainly because the accident occurred at a location close to the operator's residence. It can be seen that the accident location was within .6 mile of the residence of half the bicyclists, and that only five percent of the accidents occurred at a location 7.6 miles or farther from the bicyclist's residence.

On the average, the accident location was farther from the motorist's residence than the bicyclist's residence; but even so, the distance between the accident location and the motorist's residence was quite small in comparison to the average one-way length of urban trips in motor vehicles.

TABLE 18

PROXIMITY OF ACCIDENT SITE TO OPERATORS' RESIDENCE

	CENTILES (MILES)				
	5TH	25TH	MEDIAN 50TH	75TH	95TH
BICYCLISTS (N=525)	.1	.2	.6	2.3	7.6
MOTORISTS (N=385)	.1	.6	2.6	6.7	26.7

For instance, it can be seen that half the cases occurred at a location no farther than 2.6 miles from the motorist's home and that 75% of the cases occurred at a location no farther than 6.7 miles from the motorist's home. Although a few of the motorists were engaged in inter-city travel, only five percent of them were farther than 26.7 miles from home when the accident occurred.

The data on the proximity of the accident location to the operator's home (Table 18) along with the data on the number of times the operators had driven through the accident site before the accident occurred (Table 6) clearly show that only a small number of the operators were traveling through an unfamiliar area at the time the accident occurred. These findings probably reflect the travel patterns of bicyclists and motorists indicating that both bicyclists and motorists spend most of their time traveling in familiar locations.

It is altogether possible that accident likelihood could be far greater when an operator is traveling in an unfamiliar location. Conversely, it is possible that accident likelihood is lower in unfamiliar locations because the operators exercise more caution than they do when traveling in areas they are thoroughly familiar with. Although these data do not enable one to judge the relative accident likelihood for familiar and unfamiliar areas, they do enable one to confidently conclude that lack of familiarity with the accident site is seldom a factor in bicycle/motor-vehicle accidents.

TRAFFIC CONTEXT

The general traffic contexts in which the accidents occurred are described below in terms of the type of traffic location, roadway class, posted speed limit, roadway alignment, and the type and condition of the roadway surface. Because it was not possible to conduct the on-site investigation until several months after the accident occurred, the data compiled on operating speed and traffic volume cannot be considered reliable; so they will not be presented here. Data on the contributory effects of vehicle speed and traffic volume will be discussed in Section V of this report.

Type of Traffic Location

The location of the accident site was described above in terms of non-traffic parameters--land use in the vicinity of the accident site and proximity of the accident site to the operators' residences. The location of the accident site is described below in terms of the general traffic context in which the accident occurred. The accidents were classified in accordance with the types of locations listed below.

- Signed intersection[12]
- Signalized intersection
- Commercial driveway/roadway junction
- Residential driveway/roadway junction
- Alley/roadway junction
- Uncontrolled intersection
- Parking lot
- Non-intersection

To better characterize the location of the accident site within the traffic environment, the accident cases were further subdivided into three groups based upon the pre-crash paths of the vehicles. One group includes all the accidents in which the vehicles' pre-crash paths were orthogonal. A second group includes accidents in which the vehicles' pre-crash paths were parallel (facing approach or same direction) and one vehicle turned across the path of the other immediately prior to the crash. The third

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[12]An accident was classified into an intersection category only if the presence of the intersection or junction influenced the accident in some way.

group includes accidents in which the vehicles' pre-crash paths were orthogonal and the collision course was not the result of an overt turning movement by one of the vehicles. Table 19 shows the distributions of traffic locations for rural and urban accidents and for fatal and non-fatal accidents.

TABLE 19

TYPE OF TRAFFIC LOCATION FOR URBAN AND RURAL ACCIDENTS

TYPE OF TRAFFIC LOCATION	RURAL FATAL (N=52)	RURAL NON-FATAL (N=112)	URBAN FATAL (N=114)	URBAN NON-FATAL (N=637)
ORTHOGONAL PRE-CRASH PATH				
SIGNED INTERSECTION	7.7%	8.6%	12.2%	22.9%
SIGNALIZED INTERSECTION	1.9%	.9%	7.0%	10.5%
COMMERCIAL DRIVEWAY/ROADWAY JUNCTION	1.9%	3.4%	1.8%	8.5%
RESIDENTIAL DRIVEWAY/ROADWAY JUNCTION	3.8%	8.6%	11.4%	7.4%
ALLEY/ROADWAY JUNCTION	--	--	.9%	2.8%
UNCONTROLLED INTERSECTION	--	4.3%	.9%	2.5%
BICYCLIST ENTERED ROADWAY OVER CURB/SHOULDER	3.8%	2.6%	3.5%	2.5%
PARKING LOT	--	--	.9%	.9%
PARALLEL PRE-CRASH PATH, SUDDEN TURN				
SIGNED INTERSECTION	1.9%	3.4%	1.8%	8.9%
SIGNALIZED INTERSECTION	--	.9%	3.5%	6.0%
COMMERCIAL DRIVEWAY/ROADWAY JUNCTION	--	1.7%	.9%	3.6%
RESIDENTIAL DRIVEWAY/ROADWAY JUNCTION	--	5.2%	--	1.7%
ALLEY/ROADWAY JUNCTION	--	--	--	.6%
UNCONTROLLED INTERSECTION	--	2.6%	1.8%	2.4%
NON-INTERSECTION	11.6%	17.2%	8.8%	4.6%
PARALLEL PRE-CRASH PATH, NO OVERT TURN				
NON-INTERSECTION	67.4%	40.6%	44.6%	14.2%
COMBINED				
SIGNED INTERSECTION	9.6%	12.0%	14.0%	31.8%
SIGNALIZED INTERSECTION	1.9%	1.8%	10.5%	16.5%
COMMERCIAL DRIVEWAY/ROADWAY JUNCTION	1.9%	5.1%	2.7%	12.1%
RESIDENTIAL DRIVEWAY/ROADWAY JUNCTION	3.8%	13.8%	11.4%	9.1%
ALLEY/ROADWAY JUNCTION	--	--	.9%	3.4%
UNCONTROLLED INTERSECTION	--	6.9%	2.7%	4.9%
PARKING LOT	--	--	.9%	.9%
NON-INTERSECTION	82.8%	60.4%	56.9%	21.3%

Traffic location for rural accidents. Since the density of intersections is generally low in rural areas, it is not surprising to find that most rural accidents--82.8% of the fatal accidents and 60.4% of the non-fatal accidents--occurred at a non-intersection location. Table 19 shows that some of these accidents occurred as one of the operators, usually the bicyclist, was turning across the path of the other vehicle. About 12% of the fatal and 17% of the non-fatal accidents at non-intersection locations involved an overt turn by one of the operators. However, the majority of the accidents at a non-intersection location did *not* involve an overt turn by one of the operators (67.4% of the fatal accidents and 40.6% of the non-fatal accidents).

The proportion of accidents that occurred at a non-intersection location was found to be significantly greater ($p < .01$) for fatal than for non-fatal accidents. This finding suggests that the likelihood of fatal injuries is less at rural intersections than at other rural locations. This result is probably due to the fact that the motor vehicle's speed is, on the average, somewhat less at rural intersections than at other rural locations.

For accidents that occurred at a rural intersection, a significantly greater proportion of non-fatal than fatal accidents occurred at the junction of a residential driveway and roadway ($p < .05$) and at an uncontrolled intersection ($p < .05$). None of the other differences between fatal and non-fatal accidents (rural) differed significantly, either for the subdivided or the combined data.

Traffic location for urban accidents. A significantly smaller proportion ($p < .01$) of urban than rural accidents occurred at a non-intersection location. Even so, nearly 57% of the fatal accidents in the urban sample occurred at a non-intersection location. The difference is most dramatic for non-fatal accidents. While 60.4% of the non-fatal accidents in the rural sample occurred at a non-intersection location, the proportion of non-fatal accidents at a non-intersection location was only 21.3% for the urban sample. The difference in the proportions of fatal and

and non-fatal accidents (urban) that occurred at a non-intersection location is highly significant ($p < .01$). Other statistically significant differences in proportions for the fatal and non-fatal samples are as follows.

- A significantly larger proportion of non-fatal than fatal accidents occurred at a signed intersection ($p < .01$). The difference is significant for both the orthogonal path and the parallel path accidents.

- A significantly larger proportion of non-fatal than fatal accidents occurred at the junction of a commercial driveway and roadway ($p < .01$). The difference is significant for both the orthogonal path accidents and for the combined accidents.

Some of the accidents that occurred at signed intersections, signalized intersections, uncontrolled intersections, and junctions of roadways and driveways/alleys involved a bicyclist whose pre-crash path was on the sidewalk. For the *fatal* sample, it was found that only two of the bicyclists had been riding on the sidewalk just prior to the accident. One of the fatal accidents that occurred at a signed intersection involved a bicyclist riding into the intersection from a sidewalk, and one of the fatal accidents that occurred at a signalized intersection happened in the same fashion. Listed below are the proportions of the *non-fatal* accidents that involved a bicyclist whose pre-crash path was on a sidewalk. In computing these proportions, cases were excluded in which the bicyclist rode from a sidewalk over a curb, shoulder, or driveway apron and into the roadway.

- Signed intersection--1.9%
- Signalized intersection--.5%
- Commercial driveway/alley--2.4%
- Residential driveway--.3%
- Uncontrolled intersection--.1%

Number of Traffic Lanes

Table 20 shows the number of traffic lanes present on the roadway the vehicles were traveling prior to the collision. When the bicyclist was riding on the sidewalk prior to entering the roadway, the tabulation was based on the number of traffic lanes for the roadway that ran parallel to the sidewalk on which the bicyclist was riding. The first row in Table 20

TABLE 20

NUMBER OF TRAFFIC LANES FOR THE ROADWAY THE VEHICLES WERE TRAVELING PRIOR TO THE COLLISION

VEHICLES' PRE-CRASH PATHS	TOTAL TRAFFIC LANES											
	RURAL ACCIDENTS (FATAL = 52; NON-FATAL = 112)						URBAN ACCIDENTS (FATAL = 114; NON-FATAL = 637)					
	1-2 LANE		3-4 LANE		5-8 LANE		2 LANE		3-4 LANE		5-8 LANE	
PARALLEL PATHS	*55.8%*[1]	**60.0%**[1]	*23.2%*	**12.6%**	*3.8%*	**1.8%**	*28.1%*[2]	**27.5%**[2]	*28.9%*	**11.8%**	*5.3%*	**2.4%**
ORTHOGONAL PATHS												
1-2 LANE	*7.7%*	**10.0%**	---	**1.8%**	---	---	*7.0%*	**18.4%**	*5.2%*	**10.4%**	*.9%*	**1.6%**
3-4 LANE	---	---	---	**.9%**	---	---	---	---	*2.6%*	**5.2%**	*3.5%*	**.5%**
5-8 LANE	---	---	---	---	---	---	---	---	---	---	*.9%*	**.9%**
COMMERCIAL DRIVEWAY	*1.9%*	**1.7%**	---	**1.7%**	---	---	*.9%*	**2.7%**	*.9%*	**4.9%**	---	**.9%**
RESIDENTIAL DRIVEWAY	*3.8%*	**8.6%**	---	---	---	---	*11.4%*	**7.4%**	---	---	---	---
ALLEY	---	---	---	---	---	---	*.9%*	**2.4%**	---	**.2%**	---	**.2%**
OVER SHOULDER/CURB	*1.9%*	**.9%**	*1.9%*	---	---	---	*.9%*	**2.2%**	*1.7%*	**.2%**	*.9%*	**.2%**

[1]The percentages shown in italics are for fatal accidents; the percentages in bold type are for non-fatal accidents.

[2]Includes two fatal and six non-fatal cases that occurred within a paved parking lot. Also includes one case in which both vehicles were traveling on the same residential driveway.

shows the percentages for the accidents in which the operators were traveling parallel paths on the same roadway. The remaining cells show percentages for the accidents in which the operators' pre-crash paths were orthogonal. The percentage values in italics are for fatal accidents, and those in bold type are for non-fatal accidents.

Rural accidents. In examining the data for rural accidents, it should first be observed that the percentage values for fatal and non-fatal accidents did not differ significantly for any cell. It was noted above that most rural accidents occurred when the vehicles were on the same roadway traveling parallel paths. Examination of the first row in Table 20 shows that well over one-half of all rural accidents occurred when the vehicles were traveling parallel paths on a two-lane rural roadway (55.6% of the fatal and 60.0% of the non-fatal accidents). A much smaller percentage of the parallel-path accidents in rural areas occurred on a three- or four-lane roadway (23.2% of the fatal and 12.6% of the non-fatal accidents); and fewer still occurred on a roadway with more than four lanes (3.8% of the fatal and 1.8% of the non-fatal accidents).

The rural accidents in which the vehicles were traveling orthogonal paths occurred most frequently at the intersection of a pair of two-lane roadways or at the junction of a two-lane roadway and a residential driveway. Less than two percent of the rural accidents occurred at any other single type of junction.

Perhaps the most important conclusion to be drawn from these data is that a relatively small proportion of the rural accidents occurred on a rural roadway with more than two traffic lanes. Tabulating across cells in Table 20 will show that only 28.9% of the fatal accidents and 18.8% of the non-fatal accidents occurred when one or both vehicles were traveling on a rural roadway with more than two traffic lanes. This finding does not indicate that it is more safe to ride a bicycle on a multi-lane roadway when traveling in a rural area. Rather, it indicates that most bicycle riding in rural areas is done on a two-lane roadway.

Urban accidents. It can be seen in Table 20 that there are substantial differences between the distributions of urban and rural accidents. The main differences are that the relative proportion of parallel-path accidents is significantly smaller ($p < .01$) for urban than for rural accidents; and a significantly larger proportion ($p < .01$) of urban accidents occurred when one or both vehicles were traveling a roadway with more than two lanes. The fatal and non-fatal accidents that occurred in an urban area are distributed similarly, but there are several differences that proved to be statistically significant, including:

- For parallel-path accidents, a significantly larger proportion ($p < .01$) of fatal than non-fatal accidents occurred on an urban roadway with three or four lanes.
- For orthogonal-path accidents, a significantly smaller proportion ($p < .01$) of fatal accidents occurred at the junction of a pair of two-lane roadways and at the junction of a commercial driveway and a three- or four-lane roadway.
- A significantly greater proportion ($p < .01$) of fatal accidents occurred at the junction of a three- or four-lane roadway and a roadway with more than four lanes. In addition, a significantly larger proportion ($p < .01$) of fatal accidents occurred when a bicyclist rode over a curb or shoulder into a roadway with three or four lanes.

All of the above differences appear to stem from the same underlying factor. Motor-vehicle speeds tend to be greater on roadways with three or more lanes; and the likelihood of fatal injuries increases as a function of motor-vehicle speed. The strength of this relationship is discussed in more detail below.

Posted Speed Limit

The distribution of posted speed limits for the roadways the motor vehicles were traveling at the time of the accident is shown in Figure 22. The unshaded bars show the percentage of non-fatal accidents and the shaded bars the percentage of fatal accidents for each speed category. The distribution for non-fatal accidents shows that nearly three-fourths of the non-fatal accidents occurred on roadways with a posted speed limit between 20 and 35 miles per hour. This finding undoubtedly is due to the fact that the vast majority of bicycle riding is done on roadways with a posted speed limit between 20 and 35 miles per hour.

The distribution for fatal accidents is dramatically different from the distribution for non-fatal accidents. It can be seen that more than

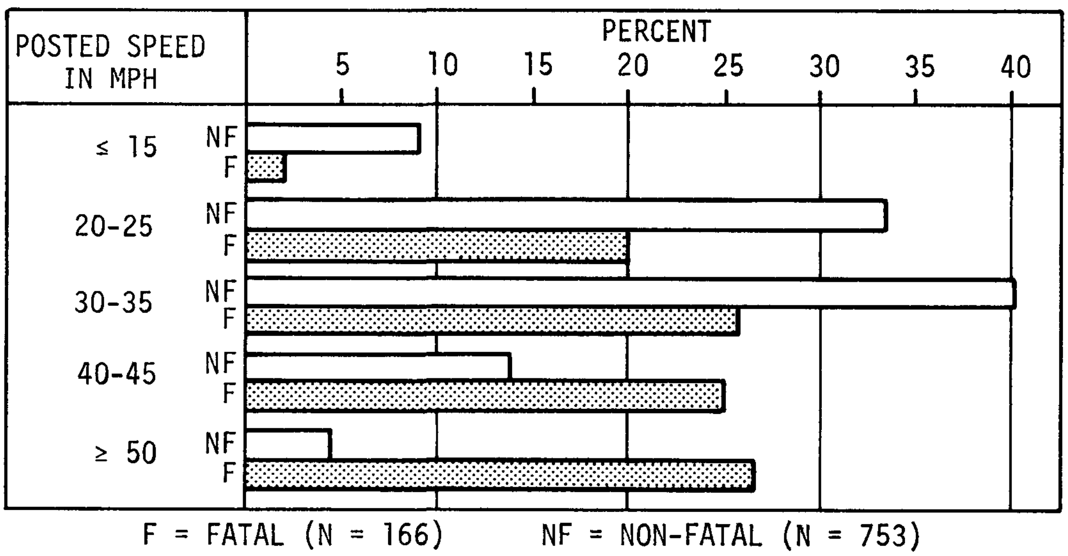

Figure 22. Distribution of posted speed limit for the roadways the motor vehicles were traveling at the time of the accident.

half of all fatal accidents occurred on roadways with a speed limit of 40 miles per hour or more and that less than one-third of the accidents occurred on roadways with a posted speed limit of 25 miles per hour or less. The percentage values for fatal and non-fatal accidents differ significantly ($p < .01$) for every speed category; so the trend shown in Figure 22 is a reliable one.

It may at first appear surprising that the proportion of fatal accidents is about the same for the three highest speed-limit categories (30-35 MPH, 40-45 MPH, and ≥50 MPH). When considering these findings, one is at first tempted to conclude that the likelihood of fatal injuries remains constant for speeds above 25 MPH. However, when the distribution for fatal accidents is compared with the distribution for non-fatal accidents, it becomes apparent that such a conclusion would be erroneous. The distribution for non-fatal accidents shows that the likelihood of an accident declines dramatically for roadways with a posted speed limit that exceeds 35 miles per hour--almost certainly because bicyclist traffic on such roadways is comparatively low. And yet, the proportion of fatal accidents remains the same for the roadways with the higher speed limits even though total exposure is far less. Therefore, one can confidently conclude that the likelihood of fatal injuries does, in fact, increase substantially on roadways with a posted speed (and a probable operating speed) above 35 miles per hour.

ROADWAY ALIGNMENT

The information for fatal accidents was often insufficient to determine the roadway alignment at the accident site. As a consequence, no conclusions can be drawn about roadway alignment at the site of the fatal accidents in the study sample. For non-fatal accidents, the vast majority occurred on a roadway with no significant lateral or vertical curvature. It was found that one or both operators' pre-crash path was on a laterally-curved roadway in only 3.6% of the non-fatal cases.

TABLE 21

OPERATORS' DIRECTION OF TRAVEL FOR NON-FATAL ACCIDENTS THAT OCCURRED ON A HILL

	DIRECTION OF TRAVEL	
OPERATOR	UPHILL	DOWNHILL
BICYCLISTS (N=753)	1.7%	8.2%
MOTORISTS (N=753)	3.3%	3.8%

The percentages of non-fatal cases that occurred on a hill are shown in Table 21. Summing across columns, it can be seen that 7.1% of the motorists and 9.9% of the bicyclists were traveling on a measurable hill at the time of the crash or shortly before the crash. For motorists, equal numbers were traveling uphill and downhill. However, a significantly larger proportion ($p < .01$) of the bicyclists were traveling downhill than uphill. This finding is undoubtedly due to the higher speeds that bicyclists travel when riding downhill. Although a relatively small proportion of the accidents occurred when the bicyclist was riding downhill, there is little question that accident likelihood is increased by the higher speeds achieved when riding downhill and the greater braking distance that is required for a given speed when riding down a hill.

ROADWAY SURFACE TYPE AND CONDITION

Table 22 shows that few accidents occurred on a roadway with an unpaved surface. For fatal accidents, none of the motorists were traveling on an unpaved roadway, and only 2.4% of the bicyclists were traveling on an unpaved driveway or roadway prior to the crash. For non-fatal accidents, 2.4% of the motorists and 2.5% of the bicyclists were traveling either on an unpaved driveway or an unpaved roadway.

The types and numbers of roadway surface defects present at the accident site are shown in Figure 23. First note that at least one roadway-surface defect was present at the site of about 12% of the fatal accidents and 11% of the non-fatal accidents. A worn and polished roadway surface was present at the site of about five percent of the fatal and non-fatal accidents, while significant bumps or cracks were present at the site of about five percent of the non-fatal and four percent of the fatal accidents.

TABLE 22

DISTRIBUTION OF CASES IN WHICH OPERATOR WAS TRAVELING ON AN UNPAVED ROADWAY

		PERCENT UNPAVED	
OPERATOR	ROADWAY	FATAL (N=166)	NON-FATAL (N=753)
BICYCLISTS	DRIVEWAY ROADWAY	1.8% .6%	.9% 1.6%
MOTORISTS	DRIVEWAY ROADWAY	-- --	.4% 2.0%

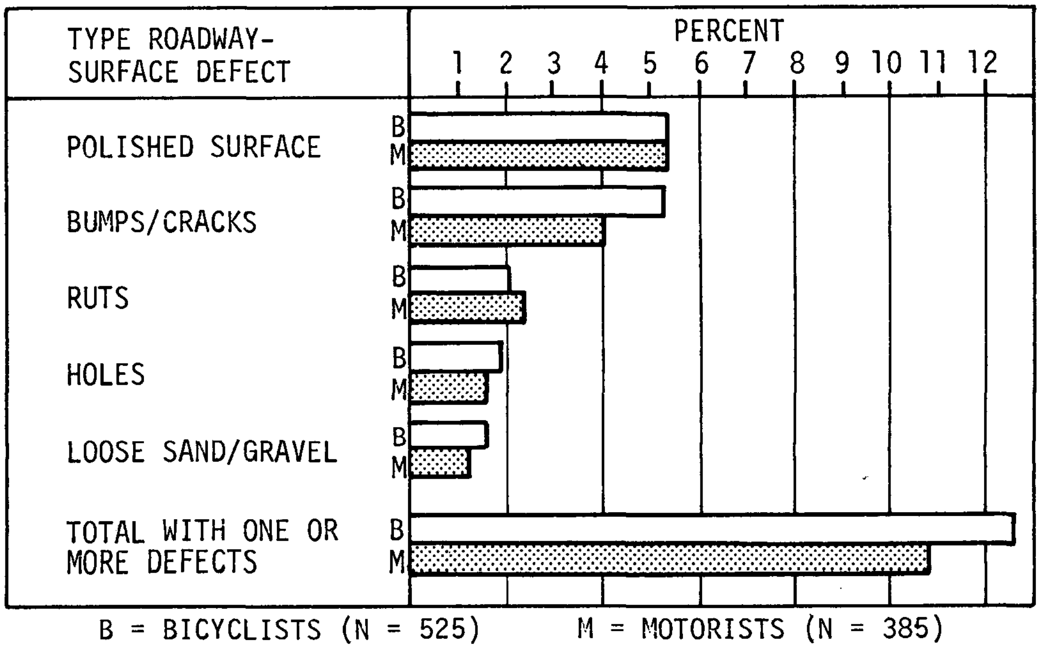

Figure 23. Distribution of surface defects for roadways the operators were traveling prior to the collision (non-fatal accident sample).

Ruts, holes, or loose sand and gravel were present at the site of between 1.2% and 2.4% of the fatal and non-fatal accidents. While these types of roadway-surface defects--particularly loose sand and gravel--constitute important hazards for bicyclists, roadway-surface defects were present at the site of a relatively small proportion of the accidents and were causal factors for an even smaller proportion of accidents.

THE ACCIDENT CONSEQUENCES

Information about injuries and property damage resulting from the accident was limited to that which could be obtained from the operator interviews. The collection and analysis of medical records and property damage documentation was beyond the scope of this study. Since few of the operators involved in fatal accidents could be interviewed, little information about the consequences of fatal accidents was compiled, other than the number of persons who were fatally injured in the accident. To the extent possible from self reports by the involved operators, an assessment was made of the type, severity, and cause of injuries sustained in the accident and the dollar cost of the property damage resulting from the accident. These data are summarized in the following paragraphs.

TOTAL NUMBER OF PERSONS KILLED OR INJURED

It is widely recognized that it is usually the bicyclist who is injured in bicycle/motor-vehicle accidents. However, Table 23 shows that motorists and passengers are sometimes injured as well. Table 23 shows that the 166 fatal cases and the 753 non-fatal cases resulted in a total of 172 persons killed and 765 persons injured. There was one case in which two bicyclists who were riding separate bicycles were killed in the same accident. This accounts for the fact that 167 bicycle operators were

TABLE 23

PERSONS KILLED AND INJURED IN THE STUDY SAMPLE OF 166 FATAL AND 753 NON-FATAL ACCIDENTS

		KILLED	INJURED
VEHICLE OPERATORS	BICYCLISTS	167	720
	MOTORISTS	1	25
VEHICLE PASSENGERS	BICYCLE	3	16
	MOTOR VEHICLE	1	4
COMBINED OPERATORS AND PASSENGERS		172	765

killed in the 166 cases. Also killed were one motorist, one motor-vehicle passenger, and three bicycle passengers. The fatally injured motorist and the fatally injured motor-vehicle passenger were riding a motorcycle at the time of the accident (separate accidents).

Information obtained from the operator interviews and from the traffic accident report forms indicated that 720 bicyclists and 25 motorists in the non-fatal sample sustained at least minor injuries in the accident. It is of interest to note that nearly one-third of the injured motorists were riding a motorcycle at the time of the accident. The 753 non-fatal cases also resulted in injuries to a total of 16 bicycle passengers and four motor-vehicle passengers.

INJURY SEVERITY

The following discussion of injury severity is based upon data obtained from the 525 bicyclists in the non-fatal sample who were interviewed. The sample of motorists and passengers was too small to enable inferences to be made about the severity of their injuries. Of the 525 bicyclists who were interviewed, 91.8% suffered injuries severe enough to cause them pain and discomfort for at least one day following the accident. The injuries sustained by 54.8% of the sample were severe enough to prevent them from going to work or school for at least one day; 17.5% of the bicyclists in the sample were hospitalized for one or more days. Based upon the injury data compiled on the sample of 525 bicyclists, a bicyclist who is involved in a bicycle/motor-vehicle accident, on the average, suffers the following consequences:

- 1.4 days in the hospital.
- 1.4 days in bed at home.
- 7.4 days missed work or school.
- 23.6 days suffering pain or discomfort.

It seemed reasonable to suppose that the single most important factor determining severity of injury is the impact velocity. To test this hypothesis, the accident cases were divided into three general categories. The mean number of days disabled and hospitalized for each of the three categories is shown in Table 24. It can be seen that severity of injury (as measured by the number of days disabled and hospitalized) is greatest when a motor vehicle traveling at sustained speed strikes the bicycle. Injury severity is less when the bicycle strikes the motor vehicle or when the bicycle is struck by a motor vehicle that is in the process of slowing or accelerating.

As will be shown in Section V, there are some types of accidents that result in a proportionately greater number of fatal injuries than others. The incidence of fatal injuries is greatest for the types of accidents in which the bicyclist is struck by a motor vehicle traveling at sustained speed, particularly on rural roadwways where the operating speed of the motor vehicle is typically above 40 MPH. Fatal injuries seldom occur when the bicyclist strikes the motor vehicle and the impact velocity is a sole function of the bicyclist's speed. The types of accidents that result in the highest incidence of fatal injuries probably result in the most severe

TABLE 24

MEAN DAYS DISABLED AND HOSPITALIZED AS A FUNCTION OF THE TYPE OF COLLISION

TYPE OF COLLISION		MEAN DAYS: DISABLED[1]	MEAN DAYS: HOSPITALIZED
MOTOR VEHICLE STRIKES BICYCLE	MOTOR VEHICLE AT SUSTAINED SPEED (N=186)	9.5	2.3
	MOTOR VEHICLE SLOWING OR ACCELERATING (N=68)	6.0	.4
BICYCLE STRIKES MOTOR VEHICLE (N=271)		6.0	.9
TOTAL SAMPLE (N=525)		7.3	1.4

[1]The number of days the injuries prevented the bicyclist from returning to work or school.

injuries for non-fatal accidents as well. However, because of the great variability of injury severity within a given type of accident and because of the relatively small sample size for this study, a reliable assessment of the differences in injury severity among types of accidents is not possible.

INJURY TYPE AND LOCATION

The bicyclists who were interviewed were requested to indicate the type and location of their most serious injuries (up to four). A checklist was provided for use in identifying injury type. The bicyclist indicated the injury location on a set of standard drawings of the human body (front and rear views of the body surface and the skeletal system--see Appendix B, pp. B-112-B-115). The 525 bicyclists identified 1,314 injuries--an average of 2.5 injuries per bicyclist. The type and location of the sample of injuries are discussed below.

Injury Type

The analysis revealed that 76.4% of the injuries were body-surface injuries, 17% were skeletal injuries, and six percent were internal non-skeletal injuries. The relative incidence of the most frequently occurring types of injuries is shown in Figure 24. It can be seen that abrasions and bruises together accounted for nearly two-thirds of the injuries while about 11% of the injuries were lacerations. Considering next the skeletal injuries, it can be seen that 7.5% of the injuries were fractures, 5.6% were sprains, 2.7% were concussions, .9% were dislocations, and .6% were broken teeth. Nearly five percent of the injuries were aches and pains in the muscles and joints, and slightly over one percent were ruptures of sub-cutaneous tissue, arteries, vessels, or organs.

The finding that about three-fourths of the injuries were body-surface injuries suggests that protective clothing has the potential for reducing or eliminating many of the types of injuries sustained by the bicyclists. Protective clothing also has the potential for reducing or eliminating

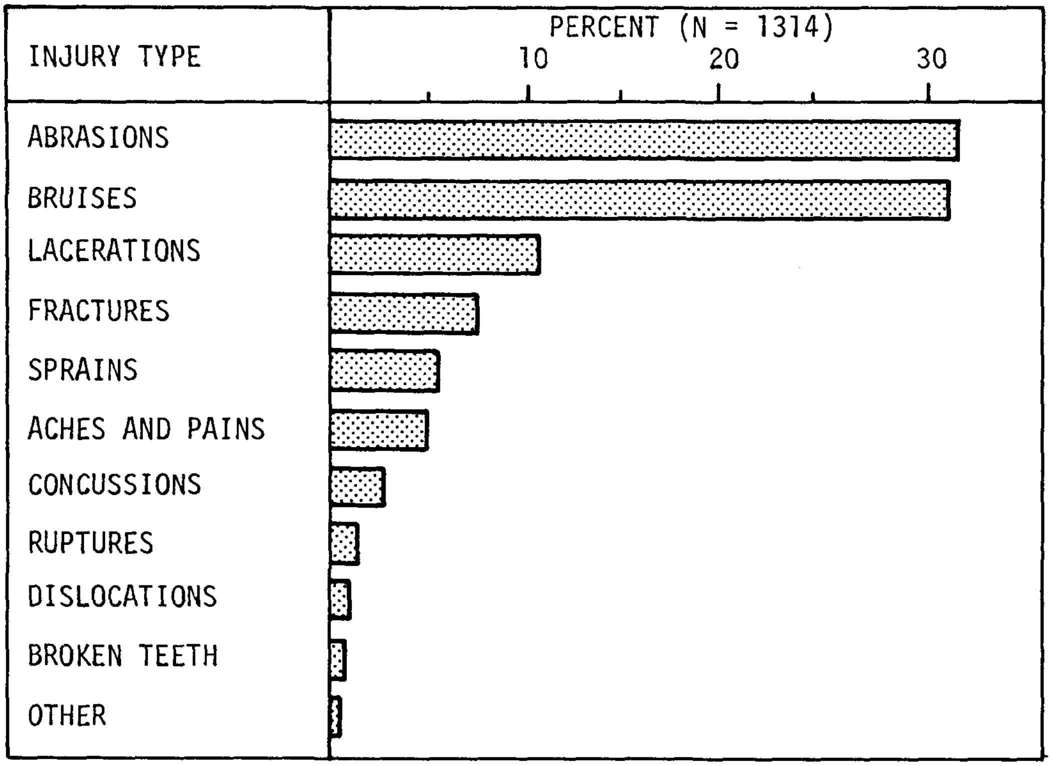

Figure 24. Distribution of injury types for bicyclists in the non-fatal sample.

concussions and possibly other types of fractures as well. Readers who have an interest in injury type should refer to Appendix D-1 which shows a more detailed breakout of injury type. Table D-1 shows the relative frequency for each type of accident separately for the first, second, third, and fourth most serious injury. In addition, the table provides a more detailed breakout of the types of fractures that occurred.

The distribution of injuries for fatal accidents would certainly be different from the distribution of injuries for non-fatal accidents. Other research indicates that the relative frequency of head injuries and internal injuries would be much greater for fatal than non-fatal accidents. For instance, autopsies performed on 181 bicyclists killed in traffic accidents during the period 1935-1963 (Tonge, O'Reilly, Davison, & Derrick, 1964) showed that brain damage was evidenced in over 80% of the fatalities with an associated skull fracture occurring in 71% of the cases. Injury to abdominal organs was found in over 50% of the victims. Similar findings are reported by Bowen (1970) and by Gissane, Bull, and Roberts (1970).

The distribution of type of injury found in this study is highly similar to the distribution of type of injury sustained by bicyclists treated in NEISS hospital emergency rooms during the period between 1969 and 1974. In the NEISS sample, it was found that abrasions, bruises, and lacerations accounted for about 70% of the injuries; fractures accounted for approximately 13% of the injuries; skull fracture was evident in less than .5% of the cases, while concussions and organ injuries occurred in less than 3% and .4% of the cases, respectively (Consumer Product Safety Commission, 1975). Information obtained by the CPS Commission from death certificates indicates that head and neck injuries were present in 80% of the fatal cases.

Injury Location

The reader who is interested in the exact distribution of injury location is referred to Appendix D-1 (pp. D-164-D-190) which shows scatter plots of the exact location of the three most serious injuries sustained by the bicyclists who were interviewed. Separate scatter plots are provided for each of the seven classes of accidents that are defined in the next section (Section V).

The primary reason for examining the location of injuries is to evaluate the potential of different types of protective clothing for reducing the number and severity of injuries resulting from bicycle/motor-vehicle accidents. Rough dimensions of various types of protective clothing were defined, and tabulations were made of the proportion of the injuries that falls within the boundaries of each type of protective clothing. (Actually, the padding of various parts of the body could be incorporated into one or two separate garments.) Table 25 shows the proportion of body-surface injuries that would be affected by protective clothing that would pad or otherwise protect specific body regions.

TABLE 25

POTENTIAL OF VARIOUS TYPES OF PROTECTIVE CLOTHING FOR REDUCING BODY-SURFACE INJURIES

TYPE OF PROTECTIVE CLOTHING	BODY-SURFACE INJURIES AFFECTED (N=1001)
KNEE PADDING	14.1%
HELMET	11.0%
ELBOW PADDING	9.2%
FACE GUARD	8.0%
SHIN PADDING	6.6%
FOOT/ANKLE PROTECTION	6.5%
GLOVES/MITTENS	6.3%
HIP PADDING	6.3%
SHOULDER PADDING	3.6%
INNER THIGH PADDING	1.0%

It can be seen that knee padding has the potential for eliminating or reducing more than 14% of the body-surface injuries. Since many of these injuries are abrasions and lacerations, it is possible that a heavy material covering the knees would effect a significant reduction in the severity of injuries to the knee. A helmet covering the upper skull has the potential for reducing injuries by 11%; another eight percent reduction could be realized by affixing a face guard on the helmet that would serve to protect the face, teeth, and chin of the bicyclist. Effective elbow padding could reduce the number of body-surface injuries by as much as 9.2%. Shin padding, foot/ankle protection, gloves/mittens, and hip padding each has the potential for reducing body-surface injuries by more than six percent. Shoulder padding could reduce body-surface injuries by as much as 3.6%, and protection of the inner thigh could reduce body-surface injuries by about one percent.

The percentage values shown in Table 25 are based only on body-surface injuries. It is possible that protective clothing would also effect a reduction in the number of skeletal injuries and other internal injuries. For instance, a helmet with a face guard has the potential for reducing the number of concusions and lost or broken teeth; effective footwear could reduce the number of ankle sprains and fractures; and effective gloves could reduce the number of fractures to the hands and fingers.

Since it is difficult to induce bicyclists to wear even a helmet, it would be extremely difficult to induce them to wear protective clothing that would be even more costly and more cumbersome than a helmet. Nevertheless, anyone concerned with the development of at-crash countermeasures must give serious consideration to the development of protective clothing that would provide protection for the body parts identified above.

CAUSE OF INJURY

For each injury identified, the bicyclist was asked to define what caused the injury. The results of the bicyclists' responses about injury cause are summarized in Figure 25. It can be seen that 60.4% of the injuries were the result of the bicyclist's impact with the roadway, while 24.1% of the injuries resulted from impact with the motor vehicle. It was surprising to find that only 6.2% of the injuries resulted from the bicyclist's impact with the bicycle he was riding. This finding suggests that padding the bicycle and eliminating the protrusions on the bicycle would have only limited potential for eliminating bicyclist injuries--at least those resulting from bicycle/motor-vehicle accidents.

The finding that most injuries are caused by the bicyclist's impact with the roadway suggests that one potentially effective at-crash countermeasure may be training the bicyclist in how to abandon his bicycle or fall in order to minimize injuries.

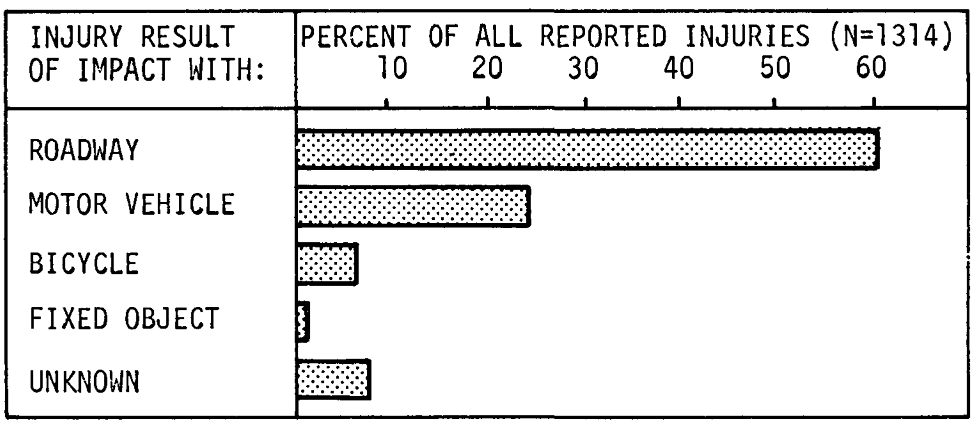

Figure 25. Cause of injury to bicyclists in the non-fatal sample.

COST OF VEHICLE DAMAGE

The bicyclists and motorists who were interviewed were asked to estimate as accurately as possible the cost of repairing the damage their vehicle incurred in the accident. Of the operators interviewed, 148 bicyclists and 77 motorists were unable or unwilling to estimate the cost of the damage to their vehicle. The distribution of cost estimates for the remaining operators is shown in Table 26. It can be seen that the median cost of bicycle damage was greater than for motor-vehicle damage, but the total range was greater for motor vehicles than for bicycles. Damage to the motor vehicle was typically very small when the damage was solely the result of the collision with the bicycle. The more costly damage to the motor vehicle occurred when the bicycle/motor-vehicle accident caused the motor vehicle to collide with another motor vehicle or with a fixed object.

These data suggest that bodily injury rather than property damage is the most significant consequence of bicycle/motor-vehicle accidents. Even so, it is estimated that the 40,000 non-fatal bicycle/motor-vehicle accidents that reportedly occur each year result in more than two million dollars in property damage. Although reliable estimates of property damage

TABLE 26

DISTRIBUTION OF COST OF VEHICLE DAMAGE SUSTAINED IN ACCIDENT

	CENTILES (DOLLARS)				
	5TH	25TH	MEDIAN 50TH	75TH	95TH
BICYCLE (N=377)[1]	\$6	\$11	\$48	\$89	\$157
MOTOR VEHICLE (N=308)[1]	\$1	\$5	\$9	\$71	\$269

[1]Of the operators interviewed, 148 bicyclists and 77 motorists were unable to estimate the cost of the damage.

could not be obtained for the fatal accidents, study of the traffic accident reports leave little doubt that the property damage is far greater for fatal than for non-fatal accidents. The bicycle is nearly always totally destroyed in fatal accidents, and the motor vehicle often subsequently collides with another motor vehicle or a fixed object. Therefore, it is not unreasonable to estimate that the annual cost of property damage resulting from bicycle/motor vehicle accidents exceeds three million dollars each year.

THE ACCIDENT CAUSES

The remainder of this section is devoted to a discussion of the factors that were found to be causally related to the accidents. In accordance with the model presented in Section II, accident causation is defined here in terms of the "function failures" that led to the accident and the "factors" that, in turn, contributed to the function failures.

The data presented below are pooled across problem types, but separate tabulations are shown for motorists and bicyclists and for fatal and non-fatal cases. Although accident causation can be most specifically and most meaningfully defined within the context of a specific problem type, presenting the data pooled across problem types serves two important purposes. First, the pooled data serve to identify causal factors that occur relatively frequently but are not a distinguishing characteristic of any one or small number of problem types. Secondly, examination of the pooled data enables one to identify and discuss factors that only infrequently contribute to bicycle/motor-vehicle accidents and to dismiss them from further consideration. It is necessary to identify factors that clearly are infrequent contributors to bicycle/motor-vehicle accidents--particularly the factors that many persons have *incorrectly assumed* were important contributors. However, when discussing specific problem types, it would be difficult to describe factors that might have contributed to the accident but did not.

PRECIPITATING FUNCTION FAILURES

According to the accident-generation model described in Section II, an accident can occur only when *both* operator-vehicle units fail to perform adequately one of the critical functions in the function-event sequence. An examination of the accidents in this sample revealed only one exception to this otherwise universal rule. There were a small number of cases in which one of the operator-vehicle units was completely stopped at an expected location in the traffic environment and was unable to initiate any type of evasive action. In these cases, it was judged that the accident was precipitated by the function failure of only the operator-vehicle unit that was moving. In all other cases, a precipitating function failure was identified for both vehicle-operator units, even though one of the operators was clearly non-culpable.

A precipitating function failure can occur either during the Anticipatory Phase or during the Reactive Phase. A precipitating function failure was said to have occurred during the Anticipatory Phase when it was judged that there was insufficient time for a normative operator to have completed all the Reactive-Phase functions once the other vehicle first became observable. A precipitating function failure during the Anticipatory Phase means that one or more of the following conditions were present: the operator's view of the other vehicle was obstructed, the visibility conditions were so poor that the other vehicle could not be observed until an accident was imminent, or the operator's pre-crash course (usually speed) was grossly suboptimal. One other reason why the precipitating failure may have occurred during the Anticipatory Phase is because the operator was unable to implement his intended course through the accident area--either because of a catastrophic vehicle failure or because the operator's response capability was seriously impaired.

Before proceeding, there is one potentially confusing issue that must be clarified. The issue concerns the assignment of a function failure when an object obstructed an operator's view of the other vehicle to such an extent that an accident was imminent once the other vehicle emerged from behind the obstructing object. This issue is complicated when attempting to define the function failure of an operator whose speed and position in the traffic lane were altogether normal for the type of roadway on which the accident occurred. The issue is exemplified by the following accident scenario.

> The motorist was proceeding along a two-way, two-lane residential roadway. The motor vehicle was traveling at a speed of 20 MPH, five miles per hour slower than the posted speed limit. There were many parallel-parked vehicles along the roadway and some of the parked vehicles masked the motorist's view of intersecting residential driveways. The motorist was driving as far from the parked vehicles on his right as was possible without entering the opposing traffic lane. As the motorist approached a driveway junction that was obscured from his view by a parked van, a young bicyclist rode into the street from the driveway. By the time the bicyclist emerged from behind the van, the vehicles were in such close proximity that the motorist had insufficient time to stop or otherwise avoid colliding with the bicyclist.

Judging from the responses of colleagues who have considered the above scenario, a *detection* failure during the Reactive Phase is the most common choice for the motorist's function failure. However, this choice is inconsistent with the model described in Section II because, by definition, the precipitating function failure must be located in the Anticipatory Phase when there is insufficient time to avoid the accident once the other vehicle first becomes observable. Moreover, the assignment of a Reactive Phase detection failure suggests that the Reactive Phase search function was performed adequately. In the above scenario, the Reactive Phase search function *could not* be performed adequately because of the visual obstruction, and there is no way to determine whether the search function *would* have been performed adequately if the obstructing object had not been present. For these reasons, it is necessary to locate the motorist's precipitating function failure in the Anticipatory Phase.

It would not be correct to state that a detection failure during the Anticipatory Phase occurred in the above scenario. The purpose of the Anticipatory Phase function is to select an optimal route through the accident area, so a detection failure occurs only when an operator fails to perceive environmental objects that are relevant for course selection. The motorist in the scenario *did* see the parked van and selected a path to avoid colliding with it. What the motorist did *not* do was to correctly evaluate the hazard associated with the van that obstructed his view of the driveway junction. That is, the motorist's function failure was an Anticipatory-Phase evaluation failure.

It can be argued that the motorist in the scenario could not be expected to behave any differently; to have avoided the accident, the motorist would have had to slow his vehicle to a crawl each time he passed a driveway that was obscured from view by a parked vehicle. It is agreed that the motorist was not at fault and that there may be no practical way to modify his behavior to effect a reduction in accident likelihood for such situations. But these facts have no bearing on the assignment of a function failure. The point is this: the Anticipatory-Phase evaluation function *was not performed adequately* in the above scenario, and the performance of the evaluation function *was necessary* for accident avoidance. This fact remains regardless of whether or not the function *could* have been performed by the operator.

In accordance with this rationale, an Anticipatory-Phase evaluation failure has been assigned when an obstruction obscured an operator's view of the other vehicle such that an accident was imminent once the other vehicle could first have been observed.

The distributions of precipitating function failures are shown in Table 27. The function failures of the bicyclists and the motorists are discussed in turn.

Bicyclists' Function Failures

Table 27 shows that the bicyclists' precipitating function failures occurred during the Anticipatory Phase in 15.6% of the fatal cases and 16.2% of the non-fatal cases. The information that was available for these cases clearly indicated that an accident was imminent at the earliest point at which the motor vehicle could have been observed by the bicyclist. However,

TABLE 27

PRECIPITATING FUNCTION FAILURES FOR BICYCLISTS AND MOTORISTS IN THE FATAL AND NON-FATAL SAMPLES

PRECIPITATING FUNCTION FAILURE		BICYCLISTS FATAL (N=166)	BICYCLISTS NON-FATAL (N=753)	MOTORISTS FATAL (N=166)	MOTORISTS NON-FATAL (N=753)
ANTICIPATORY PHASE	SEARCH	---	---	---	.1%
	DETECTION	---	---	---	.6%
	EVALUATION	---	7.7%	11.4%[1]	18.1%[1]
	DECISION	---	1.6%	---	.4%
	ACTION	4.8%	2.7%	6.0%	1.1%
	UNKNOWN	10.8%	4.2%	---	.5%
	TOTAL ANTICIPATORY	15.6%	16.2%	17.4%	20.8%
REACTIVE PHASE	SEARCH	50.0%	41.3%	21.1%	39.8%
	DETECTION	---	.4%	28.3%	9.6%
	EVALUATION	7.2%	36.0%	19.9%	23.5%
	DECISION	---	---	---	.1%
	ACTION	3.0%	3.0%	---	.3%
	UNKNOWN	24.2%	2.1%	13.3%	1.4%
	TOTAL REACTIVE	84.4%	82.8%	82.6%	74.7%
VEHICLE STATIONARY		---	1.0%	---	4.5%

[1]Nearly all evaluation failures by motorists during the Anticipatory Phase were due to the motorist's failure to assess the hazards associated with a visual obstruction.

in 10.8% of the fatal cases and 4.2% of the non-fatal cases, there was insufficient information to identify confidently the *specific* Anticipatory-Phase function that was not or could not be performed adequately by the bicyclist.[13]

[13]Since the fatal and non-fatal samples differed in the proportions of cases for which the specific function failure could be identified, it is not legitimate to test for statistically reliable differences in the distributions of function failures for the fatal and non-fatal accidents.

Anticipatory-Phase failures. Because of the sparse information available for bicyclists in the fatal sample, the only Anticipatory-Phase function failures that could be identified with a reasonable degree of certainty were action failures. The bicyclist in each of these cases lost control of his bicycle and was unable to implement his intended course--usually because of a physical impairment or because of a vehicle failure.

It can be seen that an evaluation failure during the Anticipatory Phase occurred in 7.7% of the non-fatal cases. In about one-third of these cases, the bicyclist failed to assess correctly the hazards associated with a visual obstruction; in the remaining two-thirds of the cases, he failed to assess correctly the risk associated with other aspects of his suboptimal pre-crash course. A decision failure during the Anticipatory Phase occurred in 1.6% of the non-fatal cases. In these cases, the bicyclist admitted to selecting a course that he knew was less safe than alternative courses available to him. The decision failure in all cases was due to a momentary need that was in direct competition with the need for safety. An action failure during the Anticipatory Phase occurred in 4.2% of the non-fatal cases. The action failures for the non-fatal cases occurred in the same manner as those for the fatal cases.

Reactive-Phase failures. Table 27 shows that in 84.4% of the fatal cases and 82.8% of the non-fatal cases, the precipitating function failure of the bicyclists occurred during the Reactive Phase. The information was inadequate to identify the specific Reactive-Phase failures for 24.2% of the fatal cases and 2.1% of the non-fatal cases.

It is clear that the search function and the evaluation function were the two most frequently occurring failures during the Reactive Phase. All search failures (50% of the fatal and 41.3% of the non-fatal cases) were the result of the bicyclist's failure to scan in the direction of the motor vehicle until it was too late to avoid a collision. The evaluation failures (7.2% of the fatal and 36% of the non-fatal cases) were the result of a variety of faulty expectations, assumptions, and judgments by the bicyclist. As will be discussed in more detail later, evaluation failures most frequently stemmed from the bicyclist's faulty assumption that he had been or would be observed by the motorist and that the motorist would yield the right of way to him.

The detection failures (.4% of the non-fatal cases) were due to degraded visibility conditions; the action failures (3% of both the fatal and non-fatal cases) were due to operator, vehicle, or environmental factors that prevented the bicyclist from implementing his intended evasive actions.

Summary comments. In summary, it is clear that the most frequently occurring function failures for bicyclists include: Anticipatory-Phase evaluation, Reactive-Phase search, and Reactive-Phase evaluation. A smaller, but important, number of action failures occurred during both the Anticipatory Phase and the Reactive Phase. The finding that no search or detection failures occurred during the Anticipatory Phase was due to the fact that most bicyclists were riding in an area that they had ridden through many times before. Therefore, even though the bicyclist was not carefully examining the features in the physical environment, he was thoroughly aware, from past experience, of all the relevant environmental features that were important for course selection. The lack of decision failures during the Reactive Phase also warrants brief comment. It will be recalled from Section II that a decision failure is said to occur only when the operator chooses an evasive action other than the one he perceives to be most safe. Although it is often assumed that decision failures may be exhibited by bicyclists who are defiant or inclined to take risks, not a single case was found in which the bicyclist's decision about evasive action was motivated by anything other than his own safety. When an accident appeared imminent, every bicyclist was found to be solely concerned with preserving his own skin. While competitive needs were found to influence the bicyclist's selection of a clearly unsafe course, these needs had no bearing whatsoever on the bicyclist's decision about evasive action.

A final observation is that only one percent of the non-fatal cases and none of the fatal cases occurred when the bicyclist was stopped in an expected location and was struck by the motor vehicle.

Motorists' Function Failures

Anticipatory-Phase failures. An examination of the distribution of motorists' function failures in Table 27 shows that a precipitating failure during the Anticipatory Phase occurred in 17.4% of the fatal cases and 20.8% of the non-fatal cases. It can be seen that evaluation failures are clearly the most frequently occurring Anticipatory-Phase failures. Nearly all of these accidents were due to the motorist's failure to assess the hazards associated with a visual obstruction. The rationale that led to the assignment of an Anticipatory-Phase evaluation failure for these cases was presented at the beginning of this subsection.

An action failure was the second most frequently occurring Anticipatory-Phase failure. As was true for bicyclists, the action failures occurred because the motorist was unable to implement his intended course. Action failures clearly occurred more frequently in the fatal sample (6%) than the non-fatal sample (11.1%), mainly because of the greater incidence of alcohol use by motorists in the fatal sample.

Reactive-Phase failures. In 82.6% of the fatal cases and 74.7% of the non-fatal cases, the motorist's precipitating function failure occurred during the Reactive Phase. Search, detection, and evaluation failures together accounted for most of the Reactive-Phase failures. Search failures accounted for a larger portion of non-fatal than fatal cases, and detection failures accounted for a larger portion of fatal than non-fatal cases. These differences are mainly due to the fact that a larger proportion of fatal accidents occurred at night and involved a detection failure by the motorist. While the majority of detection failures were due to a combination of darkness and inadequate bicycle lighting, some were due to the presence of precipitation or fog. As will be seen later, most of the motorists' Reactive-Phase search failures resulted from the bicyclists riding in unexpected locations in the traffic environment.

It can be seen in Table 27 that evaluation failures occurred during the Reactive Phase with about the same frequency for fatal and non-fatal accidents. The evaluation failures usually resulted from a faulty assumption by the motorist that he had been seen by the bicyclist and that the bicyclist would initiate effective evasive action. Decision failures and action failures by motorists were found to occur only infrequently during the Reactive Phase.

It was found that 4.5% of the accidents occurred when the motorist was stopped in an expected location and was struck by the bicyclist. In some cases of this type, the motorist observed the bicyclist and successfully completed all the Reactive-Phase functions. That is, the motorist observed that the bicycle and motor vehicle were on a collision course and successfully brought his vehicle to a complete stop before the collision occurred. In other instances, the motorist was stopped at a traffic signal, parked in a legal parking space, or was standing in a queue of other motor vehicles when the bicyclist collided with the standing motor vehicle. As was stated earlier, it was judged that these cases involved no function failure by the motorist.

PREDISPOSING FUNCTION FAILURES

There were some cases in which an operator's suboptimal course led directly and immediately to the accident. Because of the operator's suboptimal pre-crash course, one or both operators had insufficient time to successfully complete the Reactive-Phase functions once the other vehicle first became observable. In these cases, it was judged that the *precipitating* function failure occurred during the Anticipatory Phase.

There were many other cases in which an operator's suboptimal course was not the most immediate cause of the accident, but contributed to the accident by a) decreasing the time and space that was available to complete the Reactive-Phase functions or b) by increasing the level of skill required to complete the Reactive-Phase functions. That is, while there was sufficient time to have successfully completed the Reactive-Phase functions once the other vehicle first became observable, doing so required far more skill or a higher level of alertness than would have been required if the suboptimal course had not been present. The operator's suboptimal pre-crash course was considered a predisposing factor in such cases, so it follows that the function failures that led the operator to select the suboptimal pre-crash course represent *predisposing function failures*. By definition, all predisposing function failures occur during the Anticipatory Phase. A *predisposing* function failure was said to have occurred when the following conditions were present:

- The operator's pre-crash course (path and/or speed) was clearly less safe than alternative courses that could have been chosen.
- The alternative courses were ones that a normative operator would consider practical and otherwise acceptable.
- The operator's suboptimal course significantly decreased the time available for completing the Reactive-Phase functions and/or increased the skill level or the level of alertness required to complete the Reactive-Phase functions.
- There *was* sufficient time for the operator to have avoided the accident if all the Reactive-Phase functions had been performed in an optimal fashion.

The distributions of predisposing function failures for both the bicyclists and the motorists are shown in Table 28. It can be seen that a predisposing function failure by the bicyclist was identified in 41.6% of the fatal cases and 57.3% of the non-fatal cases. A predisposing function failure by the motorist occurred far less frequently. It can be seen that a predisposing function failure by the motorist occurred in 15% of the fatal cases and 9.4% of the non-fatal cases. The differences between these percentage values and the percentage of cases in which a suboptimal pre-crash course was present (shown in the block directly below the total predisposing failures) represent the percentages of cases in which the operator's pre-crash course was suboptimal *and* the precipitating function failure occurred during the Anticipatory Phase.

Although it was often relatively easy to determine that an operator's pre-crash path was suboptimal, it was far more difficult to identify the specific Anticipatory-Phase function failure that caused the operator to adopt the suboptimal course. Thus, the specific Anticipatory-Phase function failure could not be confidently identified in a substantial number of cases. However, based on the cases in which the specific failure could

TABLE 28

PREDISPOSING FUNCTION FAILURES FOR BICYCLISTS AND MOTORISTS IN THE FATAL AND NON-FATAL SAMPLES

	BICYCLISTS		MOTORISTS	
PREDISPOSING FAILURE	FATAL (N=166)	NON-FATAL (N=753)	FATAL (N=166)	NON-FATAL (N=753)
SEARCH	---	.5%	---	.1%
DETECTION	---	---	---	---
EVALUATION	1.8%	24.4%	4.2%	4.0%
DECISION	1.8%	5.2%	1.2%	1.1%
ACTION	---	1.3%	.6%	.3%
UNKNOWN	38.0%	25.9%	9.0%	3.9%
TOTAL PREDISPOSING FAILURES	41.6%	57.3%	15.0%	9.4%
TOTAL SUBOPTIMAL PRE-CRASH COURSE	51.8%	69.3%	21.1%	11.3%

be determined, it is clear that "evaluation" was the most frequently occurring predisposing function failure. As would be expected, most evaluation failures stemmed from the operator's faulty assessment of the degree of risk associated with his suboptimal course. A small, but significant, number of decision failures occurred, indicating the presence of a momentary need that was in direct competition with the need for safety.

ATTRIBUTES OF SUBOPTIMAL PRE-CRASH COURSES

In Section V, the description of individual problem types provides a clear indication of the attributes of the operators' pre-crash course that were suboptimal. However, since many of the attributes were not unique to a single problem type, it is informative to examine a composite summary of the attributes--pooled across problem types.

The attributes of the bicyclists' pre-crash course that were judged suboptimal are listed in Table 29. Table 30 lists the attributes of the

TABLE 29

ATTRIBUTES OF BICYCLIST'S PRE-CRASH COURSE THAT WERE JUDGED SUBOPTIMAL

SUBOPTIMAL ATTRIBUTES OF PRE-CRASH COURSE	FATAL (N=166)	NON-FATAL (N=753)
POSITION IN TRAFFIC LANE		
TRAVELING AGAINST THE FLOW OF TRAFFIC	4.8%	19.1%**
PATH UNNECESSARILY FAR FROM CURB/SHOULDER	4.8%	4.4%
RIDING ON SIDEWALK	1.8%	3.6%
RIDING IN CROSSWALK	.6%	.5%
PATH UNNECESSARILY CLOSE TO PARKED MOTOR VEHICLES	---	.4%
OTHER	---	.4%
TRAVELING TOO FAST FOR CONDITIONS		
GENERAL	6.0%	12.9%**
HILL	4.8%	5.4%
FAULTY/WET BRAKES	---	2.7%*
DARKNESS	---	2.4%*
ROADWAY-SURFACE CONDITION	---	1.3%
OPERATOR IMPAIRMENT	---	.5%
FOG/RAIN	---	.3%
OVERT TURNS		
SUDDEN AND UNEXPECTED LEFT TURN	9.6%	10.1%
UNUSUAL/UNEXPECTED PATH	3.0%	.7%**
SPEED CONTROL WHEN ENTERING ROADWAY FROM DRIVEWAY, ALLEY, OR OVER CURB/SHOULDER		
FAILED TO SLOW/STOP--NO VISUAL OBSTRUCTION	7.2%	6.1%
FAILED TO SLOW/STOP--VISUAL OBSTRUCTION PRESENT	7.2%	7.4%
SPEED CONTROL AT SIGNALIZED INTERSECTION		
FAILED TO SLOW/STOP--NO VISUAL OBSTRUCTION	4.2%	6.1%
FAILED TO SLOW/STOP--VISUAL OBSTRUCTION PRESENT	---	.4%
SPEED CONTROL AT SIGNED INTERSECTION		
FAILED TO SLOW/STOP--NO VISUAL OBSTRUCTION	7.2%	4.9%
FAILED TO SLOW-STOP--VISUAL OBSTRUCTION PRESENT	.6%	3.6%*
SPEED CONTROL AT UNCONTROLLED INTERSECTION		
FAILED TO SLOW SUFFICIENTLY--NO VISUAL OBSTRUCTION	---	1.9%
FAILED TO SLOW SUFFICIENTLY--VISUAL OBSTRUCTION PRESENT	---	2.7%*
OVERTAKING AND PASSING		
PASSING ON RIGHT AT INTERSECTION	1.2%	1.3%
OTHER	---	.7%
OTHER		
CROSSING TRAFFIC LANES BETWEEN STANDING VEHICLES	---	.4%
OTHER	---	.3%

*Proportions for the fatal and non-fatal samples are significantly different ($p < .05$).

**Proportions for the fatal and non-fatal samples are significantly different ($p < .01$).

motorists' pre-crash course that were judged suboptimal. The percentage values shown in these tables represent the percentage of cases in the total sample (fatal and non-fatal) for which the associated attribute was present. Since a single course may have had more than one suboptimal attribute, the sum of the percentage values in a column exceeds the percentage of cases in which a suboptimal pre-crash course was present (see the bottom of Table 28 for the percentage of cases in which a suboptimal course was present).

Suboptimal Attributes of Bicyclists' Pre-Crash Course

When examining the data in Table 29, it should be kept in mind that the bicyclist's course was judged suboptimal only if safer alternative courses were available, and only if it was judged that a safety-conscious bicyclist would have selected an alternate course under the conditions that prevailed at the time of the accident. Riding in the center of a traffic lane did not necessarily constitute a suboptimal course. However, riding in the center of a high-speed traffic lane is not a course that a safety-conscious bicyclist would select, particularly at night and when riding a bicycle with inadequate lighting. So, riding in the center of a traffic lane under such circumstances would be considered a suboptimal course. The same criteria were used in evaluating courses that involved riding on the sidewalk, riding in the crosswalk, riding at high speeds, and so on.

Since the data presented in Table 29 are straightforward and easy to interpret, the supporting discussion will be limited to a few brief explanatory comments.

- Traveling against the flow of traffic was a factor in 4.8% of the fatal and 19.1% of the non-fatal cases. The main reason that traveling against the flow of traffic proved suboptimal was because this path placed the bicyclist in an unexpected location--a location in the traffic environment that is seldom searched by motorists.
- In most cases in which the bicyclist was considered to have been riding unnecessarily far from the curb or shoulder, the bicyclist's course was judged suboptimal only if the visibility conditions were poor, the operating speed of motor vehicles traveling the roadway was high, or both.

- Riding on the sidewalk was judged to be a suboptimal course only when the bicyclist's view of intersecting driveways, alleys, or roadways was obstructed. Even then, the bicyclist's course was judged suboptimal only if his speed was considered too fast for the conditions that were present at the accident location.
- There were many cases in which the bicyclist's speed was judged to be too fast for the *general* conditions (roadway configuration and traffic) that existed at the time and location of the accident. In other cases, it was judged that the bicyclist's speed was too fast for a specific condition that existed at the time or location of the accident. It can be seen that separate tabulations were made for the cases that involved a bicyclist who was riding downhill at an excessive speed, riding excessively fast with faulty or wet brakes, riding excessively fast during darkness, riding too fast for the roadway surface conditions, and so on.
- It was frequently found that the bicyclist adopted a suboptimal course when executing a turn. In most instances, the course was suboptimal because the bicyclist initiated his turn suddenly and without warning, often at a location where a motorist would not expect a bicyclist to turn. In a much smaller number of cases, it was the specific path that was suboptimal (wide turns, cutting a corner, and so on).
- One of the most frequently occurring attributes of bicyclists' suboptimal courses was speed control at intersections. As is shown in Table 29, speed control was a problem at the junctions of a driveway/alley and a roadway, at signed and signalized intersections, and at uncontrolled intersections (two roadways). In many cases, the problems created by the bicyclist's failure to slow or stop were compounded by the presence of visual obstructions that prevented or degraded the operator's view of the other vehicle. Consequently, the percentage of cases in which a visual obstruction was a factor is shown separately in Table 29. Pooled across all intersection types, speed control at intersections was found to be a factor in 26.4% of the fatal and 33.1% of the non-fatal accidents.

Suboptimal Attributes of Motorists' Pre-Crash Course

Since the motorist's pre-crash course was judged suboptimal far less often than the bicyclist's course, the percentage values shown in Table 30 are much smaller than those shown in Table 29. When the motorist's pre-crash course was judged suboptimal, the most frequent reasons were because the motorist was traveling too close to the edge of the roadway or because the motorist was traveling too fast for conditions. It can be seen that

TABLE 30

ATTRIBUTES OF MOTORISTS' PRE-CRASH COURSE THAT WERE JUDGED SUBOPTIMAL

SUBOPTIMAL ATTRIBUTES OF PRE-CRASH COURSE	FATAL (N=166)	NON-FATAL (N=753)
POSITION IN TRAFFIC LANE		
PATH UNNECESSARILY CLOSE TO EDGE OF ROADWAY	8.4%	2.1%**
TRAVELING AGAINST THE FLOW OF TRAFFIC	.4%	.6%
SPEED CONTROL WHEN ENTERING ROADWAY FROM DRIVEWAY/ ALLEY		
FAILED TO SLOW/STOP--NO VISUAL OBSTRUCTION	.1%	---
FAILED TO SLOW/STOP--VISUAL OBSTRUCTION PRESENT	.8%	---
SPEED CONTROL AT SIGNALIZED INTERSECTION		
FAILED TO SLOW/STOP--NO VISUAL OBSTRUCTION	.9%	.6%
FAILED TO SLOW/STOP--VISUAL OBSTRUCTION PRESENT	.1%	---
SPEED CONTROL AT SIGNED INTERSECTION		
FAILED TO SLOW/STOP--NO VISUAL OBSTRUCTION	.7%	.6%
TRAVELING TOO FAST FOR CONDITIONS		
GENERAL	4.1%	7.8%
PHYSICAL IMPAIRMENT	7.8%	.7%**
DARKNESS	6.0%	.7%**
ROADWAY-SURFACE CONDITION	---	.7%
OVERT TURNS		
UNUSUAL/UNEXPECTED PATH	1.2%	.7%
SUDDEN/UNEXPECTED TURN	---	.3%
OVERTAKING AND PASSING		
OVERTAKING AND PASSING A MOTOR VEHICLE STOPPED AT A CROSSWALK	---	.8%
OTHER	.6%	---
OTHER		
STOPPED IN UNEXPECTED LOCATION	---	.5%

**Proportions for the fatal and non-fatal samples are significantly different ($p < .01$).

these attributes were present in a significantly larger proportion of fatal than non-fatal cases.

The motorist's path was judged to be too close to the edge of the roadway only if there was ample space for the motorist to have passed the bicyclist without entering an adjacent parallel or opposing lane of traffic. There were few instances in which the motorist's speed exceeded the posted speed limit. However, there were a substantial number of cases, particularly for fatal accidents, in which the motorist was clearly traveling too fast for the conditions that existed at the accident location and/or the operator's physical condition at the time of the accident.

There were relatively few cases in which the motorist's course was suboptimal because of his speed control when entering an intersection. Although many accidents occurred because the motorist entered an intersection and collided with a bicyclist who had the right of way, most of the motorists involved in this type of accident stopped or slowed at the intersection and proceeded only because they failed to observe the bicyclist.

FACTORS CONTRIBUTING TO FUNCTION FAILURES

Table 31 lists the general types of factors that were found to contribute to the operators' function failures. A more detailed breakdown of the contributing factors is presented in Appendix D-2. More specific information about contributing factors is presented in Section V where the causes of specific problem types are described.

While every attempt was made to develop interview procedures that would reveal the full complement of contributory factors for an accident case, it is altogether unrealistic to expect that every factor contributing to an accident could be identified by even the most successful investigation. The failure to identify important contributory factors may result from the operator forgetting pertinent facts, response biases of the operator, and failure by the Field Investigator to question the operator about germane conditions and events. The identification of contributory factors is even more difficult when an interview was not possible. When an

TABLE 31

FACTORS CONTRIBUTING TO PRECIPITATING FUNCTION FAILURES

	BICYCLISTS		MOTORISTS	
FACTORS CONTRIBUTING TO PRECIPITATING FAILURE	FATAL (N=70)[1]	NON-FATAL (N=623)[1]	FATAL (N=124)[1]	NON-FATAL (N=669)[1]
FAULTY EXPECTATIONS/ASSUMPTIONS	70.0%	62.3%	27.4%	59.5%
OPERATOR DISTRACTIONS	10.0%	25.5%	7.3%	11.9%
FAULTY JUDGMENTS	2.8%	7.2%	3.2%	5.1%
TEMPORARY OPERATOR IMPAIRMENT	2.9%	2.1%	18.5%	3.6%
PERMANENT OPERATOR IMPAIRMENT	1.4%	1.0%	.8%	.5%
INFORMATION OVERLOAD	---	2.9%	.8%	1.5%
COMPETING NEEDS	1.4%	7.2%	1.6%	1.4%
DEGRADED VISIBILITY	---	.3%	34.7%	9.9%
VISUAL OBSTRUCTIONS	---	2.1%	19.4%	21.2%
VEHICLE HANDLING SKILL DEFICIENCY (LEADING TO LOSS OF CONTROL)	4.3%	2.4%	---	.1%
OPERATOR/VEHICLE INCOMPATIBILITY (LEADING TO LOSS OF CONTROL)	---	.7%	---	---
MISUSE OF VEHICLE (LEADING TO LOSS OF CONTROL)	4.3%	2.4%	---	.7%
VEHICLE FAILURE (LEADING TO LOSS OF CONTROL)	---	2.1%	---	.3%
VEHICLE HANDLING DEGRADED BY ENVIRONMENT (LEADING TO LOSS OF CONTROL)	4.3%	1.4%	---	.3%
PRIOR COLLISION	1.4%	1.0%	.8%	---

[1]The N on which the percentages are based is the number of cases for which enough information was available to identify at least one contributory factor.

operator was killed in the accident or when an operator refused the interview, the only sources of information about contributory factors were the official traffic accident report, the interview with the surviving operator, and interviews with witnesses. While such sources of information are useful in defining the traffic context and the operator's pre-crash actions, they seldom provide useful information about *why* the operator behaved the way he did.

The net result is that the sampling error in identifying contributory factors is not random. There may be cases in which a factor is erroneously assumed to be causally related to the accident. But more often, for the reasons mentioned above, there will be contributory factors that simply were not revealed by the investigation. In short, underestimates of the incidences of a given contributory factor are far more likely than overestimates.

For these reasons, the data presented here must be considered conservative estimates of the proportion of cases in which the contributing factors were present. If the data indicate that a factor was present in a large number of cases, it can confidently be concluded that the factor is an important one, since a factor was not judged contributory unless there was reasonably strong evidence that it was present and did, in fact, contribute to a function failure. On the other hand, a factor that was found to be present only infrequently may be far more important than is indicated by the data. For instance, there is little question that nonprescribed drugs were present and contributed in more cases than were identified by this study. Unless the presence of drugs was clearly established by the investigating officer, it is unlikely that an operator would admit to having been under the influence of drugs at the time the accident occurred--whether or not the drugs contributed directly to the accident.

One other fact should be kept in mind when interpreting the data on contributory factors. It was found that environmental and vehicular factors contributed to accidents in two different ways. In some instances, the environmental and vehicular factors contributed to loss of control of the vehicle. More frequently, however, the environmental and vehicular factors served as a distraction or were one of several factors contributing to overload of the operator's information-processing capacity.

The percentage values shown in Table 31 are based on the number of cases for which enough information was available to identify at least one contributory factor. These N's represent the number of cases in which a factor had a reasonable chance of being identified, and using them to compute the percentage values partially offsets the sampling bias discussed above. The remainder of this section is devoted to observations and explanatory comments concerning the data presented in Table 31.

Faulty Expectations and Assumptions

Faulty expectations and assumptions were the most frequently occurring contributory factors for both bicyclists and motorists in both the fatal and non-fatal samples. The operators' faulty expectations and assumptions most often contributed to search failures in the Reactive Phase or evaluation failures in either the Anticipatory or Reactive Phase. It is suggested that the reader refer to the tables in Appendix D-2 to gain a full appreciation of the wide range of faulty expectations and assumptions that were found to be contributory and the relative frequency with which they occurred. The following brief descriptions exemplify the most frequently occurring types of faulty expectations and assumptions.

- The operator incorrectly assumed that traffic on all intersecting roadways would yield to him, so felt no necessity to search for traffic approaching on these roadways. This incorrect assumption was *not* the result of a misinterpretation of the right-of-way rules; the right of way *did* belong to the operator who assumed that intersecting traffic would yield to him.
- The operator failed to search in the direction of the other vehicle because it was traveling in an unexpected location, approaching from an unexpected direction, or both. In most of the cases in which this contributory factor was present, it was a motorist who failed to search in the direction of a bicyclist who was riding on the wrong side of the roadway or (less often) riding on the sidewalk.
- The other vehicle turned unexpectedly. The operator observed the other vehicle, but incorrectly assumed that it would proceed straight ahead.
- The operator observed that the operator of the other vehicle had searched in his direction and, therefore, assumed incorrectly that he had been seen by the other operator.

- The operator incorrectly assumed that a stopped vehicle would remain stationary until he had cleared the collision path. The operator assumed that he had been or would be seen by the other operator; but unlike the faulty assumption described above, this assumption was *not* based on an observation of the search pattern of the other operator.
- The motorist scanned in the direction of a clearly visible bicyclist but failed to observe it--presumably because he did not expect to encounter bicycles in the area (perceptual set, selective perception, or other similar terms may be used to describe this phenomenon).
- The bicyclist failed to search in the direction of the other vehicle because he assumed (incorrectly) that a riding companion would search for hazards and select a safe course.
- The operator incorrectly assumed that the immediate area would be void of all traffic.
- The operator anticipated a turn by the other vehicle, but incorrectly assumed that it would turn in the opposite direction.

Operator Distractions

Search failures were often due to the presence of specific distractions. It was found that the most frequently occurring distractor for bicyclists was another person with whom the bicyclist was interacting--usually another bicyclist. The most frequently occurring distractor for motorists was a vehicle or a pedestrian that the motorist considered an accident threat. Other distractors that were revealed by the study include: mental activity (non-traffic related); abnormal street surface conditions; operation of an unfamiliar vehicle; precipitation; carrying an object in hands (bicyclist only); malfunctioning vehicle; and scenic attractions. The proportion of cases in which the above distractors (and others) were found contributory is shown in Appendix D-2.

Faulty Judgments

As would be expected, faulty judgments contributed to evaluation failures during either the Anticipatory or the Reactive Phase. The most common judgmental error was a misjudgment of the risk associated with a suboptimal pre-crash course. Other judgmental errors that were found contributory include: misjudged own vehicle's stopping distance, misjudged the other vehicle's speed, misjudged the lateral space required to pass, misjudged the relative risk associated with alternative evasive actions, and misjudged the length of an amber signal phase.

Temporary Operator Impairments

When an operator impairment contributed to an accident, it was most often a temporary impairment resulting from alcohol. Alcohol was a contributory factor for motorists more often than bicyclists and was more often a factor in fatal than non-fatal accidents. Other temporary operator impairments that were found to be contributory include drug use, abnormal emotional stress, and physical fatigue.

Permanent Operator Impairments

Although permanent operator impairments contributed only infrequently, it was found that a surprising number of bicyclists in both the fatal and non-fatal samples were mentally retarded or suffering from severe brain damage--1.4% of the bicyclists in the fatal sample and .8% of the bicyclists in the non-fatal sample were found to be suffering from a permanent mental impairment of this type. Other permanent impairments that were found to be contributory include impaired vision, impaired limbs, and impaired hearing.

Information Overload

Information overload was judged to be a contributory factor in a relatively small proportion of the total sample of cases. However, as is discussed in Section V, there are some problem types for which information overload was an important contributory factor. In evaluating the contributory factors for an accident case, it was found to be extremely difficult to make confident judgments about whether the operator's information-processing capacity was overloaded. Furthermore, information overload was not identified as a contributory factor unless there was clear evidence that the operator had insufficient time to perform all the traffic-related tasks that were required at the time the accident occurred. For these reasons, it is probable that the percentage values shown in Table 31 represent rather substantial underestimates of the number of cases in which information overload was a contributory factor.

When it was found that information overload was present and contributed to a function failure (usually a search failure or evaluation failure during the Reactive Phase), the information overload was seldom due to the characteristics of the traffic environment alone. More often, the information overload condition was due to the simultaneous presence of a complex traffic environment and one or more of the following factors: excessive vehicle speed, subnormal operator skill, or subnormal vehicle functioning. The finding that information overload is seldom due solely to environmental factors has important implications for countermeasures development. That is, when information overload is partially self induced, one has the option of either simplifying the traffic environment or modifying the operator behavior that partially contributed to the information overload.

Competing Needs

It was found that momentary needs which were in direct competition with the need for safety sometimes contributed to the operator's function failure. Competing needs most often contributed to an evaluation failure during the Anticipatory Phase; the competing need led the operator to select a course that was less safe than available alternatives, but was more suited to his momentary need. As can be seen in Table 31, competing needs were most often a factor for bicyclists in the non-fatal sample. A need to conserve time, a need for excitement generated by high speed, and a need to catch up with a riding companion are examples of competing needs that were found to be contributory.

Degraded Visibility

Degraded visibility was seldom a contributor to bicyclists' function failures, but often contributed to motorists' function failures--particularly motorists in the fatal sample. When degraded visibility was a factor, it always contributed to a detection failure during the Reactive Phase. Degraded visibility was seldom found to be a contributory factor during the daytime; but, when present, degraded daytime visibility resulted from sun glare, precipitation in the form of fog or rain, or deep shadows. Degraded nighttime visibility was more often a contributory factor. Nighttime visibility was degraded by darkness in combination with inadequate lighting on the other vehicle (bicycle) and inadequate street lighting. Degraded nighttime visibility was only infrequently found to be the result of glare from artificial lights.

Visual Obstructions

Reference to Table 31 shows that a visual obstruction was a contributory factor in one-fifth of the accident cases. An examination of the accident-generation process revealed that visual obstructions contributed to motorists' function failures more often than bicyclists' function failures. This finding was the result of the large difference in speeds that the vehicles were traveling when they emerged from behind the obstructing object. Because of the motorists' greater speeds and braking distances, a far greater preview time is required than for the slower-moving bicycle. Thus, in many cases, it was found that the bicyclist had sufficient time for evasive action at the point first observable, but the motorist did not.

The types of objects most frequently found to obstruct the operator's view include vegetation, parked motor vehicles, buildings/fences, and moving/standing vehicles. The operator's view was less often obstructed by an embankment, a part of the motor vehicle's structure, or street furniture.

Loss of Vehicle Control

Table 31 lists five factors that contributed to loss of vehicle control. It can be seen that a relatively small number of accidents were caused by the motorist losing control of his vehicle. When the motorist did lose control of his vehicle, it was the result of vehicle-handling skill deficiency, misuse of the vehicle, vehicle failure, or environmental factors that degraded the handling qualities of the vehicle. Accidents more often resulted from the bicyclist's loss of control of his vehicle. In examining the factors that contributed to the bicyclist's loss of control, it is of interest to note that none of the five factors listed in Table 31 was contributory in more than 2.4% of the non-fatal cases or 4.3% of the fatal cases. This finding is of particular interest since many persons assume that bicycle/motor-vehicle accidents are frequently caused by such factors. Listed below are observations that tend to disprove many current beliefs about the frequency with which these factors contribute to loss of control of the bicycle and a subsequent bicycle/motor-vehicle accident. The percentage values cited below apply only to the non-fatal cases.

- Inadequate skill in operating caliper brakes was a factor in 1.4% of the cases.
- Riding an oversized bicycle was a factor in one percent of the cases.
- In less than one percent of the cases, the bicyclist lost control of his vehicle because he was carrying an object in his hands.
- Loss of control while performing tricks or stunts was a factor in less than one percent of the cases.
- Carrying a passenger on the bicycle led to the loss of control in less than one percent of the cases.
- Loss of control because of a vehicle failure was found in about two percent of the cases. Of these, nearly all "failures" were due to faulty brakes or wet caliper brakes.
- Abnormal roadway surface conditions led to a loss of control in only 1.4% of the cases.
- A wet roadway, holes or cracks in the roadway, or loose sand or gravel on the roadway surface seldom contributed to loss of control. Each of these three factors was a contributor in about .5% of the cases.

Prior Collision

In about one percent of the cases, it was found that the bicycle/ motor-vehicle accident was preceded by a collision of one of the vehicles with another vehicle or object. In most of these cases, the bicyclist first collided with a curb or another bicyclist before veering into the path of the motor vehicle. Surprisingly, there was only one case in which the motor vehicle struck the bicyclist after first colliding with another motor vehicle.

SECTION V
DESCRIPTION OF PROBLEM TYPES AND COUNTERMEASURES

This section describes the results of the accident-classification task described in detail in Section III. It will be recalled that the objective of the classification task was to study accident cases individually and to group together accidents whose causes were sufficiently similar that they would be amenable to the same countermeasures. To convey the full range of similarities and differences among accident cases, a hierarchical classification system was developed that consisted of problem *classes*, *types*, and *subtypes*. Problem classes reflect commonality at the most general level. Problem types represent variations of accidents within the same class, and subtypes represent variations of accidents within the same type. Problem types generally provide the most useful definition of a problem for which specific countermeasures can be tailored; but for some kinds of countermeasures, problem classes or problem subtypes may constitute a more meaningful problem definition.

ORGANIZATION AND CONTENT

After a brief overview of the results of the accident-classification task, each problem type is described and discussed. For ease of exposition, problem types within the same class are discussed together in a separate subsection. Each subsection begins with a brief description of the distinguishing characteristics of the problem class and the similarities and differences among the problem types within that class. Then, each problem type in the class is described in turn. Descriptive data are presented for each problem type as required to characterize the target location(s), the target period(s), the bicyclist target group, the critical actions of the operators, the function failures, and the factors that contributed to the function failures. The bicyclist age distributions were found to vary considerably from one problem type to another, but the motorist age distributions were highly similar for all problem types.

Therefore, only bicyclist target groups are mentioned in the problem-type descriptions.

The descriptions of Problem Types 1 through 25 are accompanied by perspective drawings that illustrate the traffic contexts in which the accidents occur and the proximal pre-crash paths of both vehicles. Some drawings illustrate two or more subtypes of the same problem type. The illustration of subtypes is accomplished by showing a separate set of vehicles (a bicycle and a motor vehicle) for each subtype. Each illustration shows the percentage of fatal and the percentage of non-fatal accidents accounted for by the problem type that is illustrated. When two or more subtypes are illustrated, percentage values are shown in close proximity to each vehicle set. These percentage values show the percentage of cases *within the problem type* that is accounted for by each subtype; the combined percentage values for the subtypes shown on each illustration total 100%. Although the illustrations provide a useful aid in understanding how accidents of a given type occur, the reader is cautioned against using the illustrations to draw inferences about the characteristics of the roadway(s), the presence or absence of visual obstructions, the exact impact points, the exact collision points, and so on.

The problem-type descriptions for each class are followed by a discussion of the countermeasure approaches that appear to have the potential for reducing the incidence of one or more problem types within that class. A deliberate attempt has been made to avoid being overly restrictive when identifying countermeasure approaches. Thus, countermeasures have been listed that many readers may consider impractical or altogether impossible. The authors would probably agree with most readers' assessments of the relative merits of the countermeasures, but it was deemed more important to be comprehensive than evaluative at this stage of development.

Appendix D-3 contains a "Data Summary Sheet" for each problem type. For all problem types except Problem Type 13, a Data Summary Sheet was prepared only for the *non-fatal* cases. Except for Problem Type 13, the number of fatal cases for individual problem types was too small to warrant a separate summary sheet for fatal accidents. There were only a few instances in which the data revealed important differences between fatal and non-fatal accidents of the same problem type, and these differences are discussed in the text. Therefore, unless stated otherwise, the information presented on the Data Summary Sheets can be considered equally applicable to fatal and non-fatal accidents. The Data Summary Sheet for each problem type contains the following information.

- Target Location(s)--A description of the type of location(s) at which the accidents occurred and the proportion that occurred at each location.
- Target Period--The time period during which accident likelihood is greatest, if any.
- Target Groups--The 5th, 25th, 75th and 95th centile age is shown for both operators.
- Function Failures--The types and relative frequency of both predisposing and precipitating function failures.
- Contributing Factors--The types and relative frequency of factors that contributed to the function failures.
- Suboptimal Pre-Crash Course--The proportions of motorists and bicyclists whose pre-crash course was judged suboptimal.

OVERVIEW

The classification system that was developed consisted of seven problem classes and 36 mutually exclusive problem types; most problem types had two or more subtypes. For six of the classes (Class A through Class F), the problem types within the same class exhibit commonality in some of their important attributes. The remaining class (Class G) contains all the problem types that could not meaningfully be classified into any of the other classes. In short, commonality was *not* the basis for classifying problem types into Class G.

The information available for the non-fatal cases was sufficiently complete to enable the project staff to classify all but 14 of the accident cases into one of the 36 problem types. Thirteen of these cases were classified into an "Other" category within Class B, and the remaining case was classified into a "Type Unknown" category within Class D. The information available for the fatal cases was sufficient to classify all but 21 cases into one of the 36 problem types. Two of these cases were classified into an "Other" category within Class B, and seven cases were classified into a "Type Unknown" category within Class D. The information for 12 of the cases was so incomplete that it was not possible to classify the cases into either a problem class or a problem type.

Table 32 shows the percentages of cases in the fatal and non-fatal samples that were accounted for by each of the 25 most frequently occurring problem types. The problem types are listed in rank order, with a rank of "1" assigned to the problem type that accounted for the largest proportion of cases. Adjacent to each rank-order number is shown the problem-type identification number and the percentage of cases accounted for by that problem type. The column entitled "Cumulative Percent" shows the percentage of cases accounted for by the "N" highest ranking problem types.

It can be seen in Table 32 that a large proportion of the cases was classified into a relatively small number of problem types. For instance, the five highest ranked problem types accounted for 51.7% of the fatal cases and 42.1% of the non-fatal cases. Similarly, the ten highest ranked problem types accounted for 66.7% of the fatal cases and 63.8% of the non-fatal cases.

Although it was expected that some problem types would account for a far greater proportion of cases than others, it was somewhat surprising to find that the relative ranking of some problem types differed greatly for the fatal and non-fatal samples. Some persons have voiced the altogether reasonable assumption that the degree of injuries sustained in a bicycle/motor-vehicle accident is mainly a function of chance, and that the likelihood of fatal injuries remains more or less constant for all types of bicycle/motor-vehicle accidents. Although logically appealing, this assumption clearly is not valid. The data in Table 32 show that some problem types accounted for a far greater proportion of fatal cases than non-fatal cases. Conversely, not a single fatal case was found for some of the problem types that accounted for a large proportion of the non-fatal cases. The reasons for these large differences will become

TABLE 32

PERCENTAGE OF CASES ACCOUNTED FOR BY THE 25 MOST FREQUENTLY OCCURRING PROBLEM TYPES

	FATAL (N = 166)			NON-FATAL (N = 753)		
RANK-ORDER NUMBER	PROBLEM TYPE NUMBER	PERCENT	CUMULATIVE PERCENT	PROBLEM TYPE NUMBER	PERCENT	CUMULATIVE PERCENT
1	13	24.6	24.6	5	10.2	10.2
2	18	8.4	33.0	9	10.2	20.4
3	5	7.8	40.8	18	8.4	28.8
4	1	6.7	47.5	23	7.6	36.4
5	14	4.2	51.7	1	5.7	42.1
6	4	3.6	55.3	24	5.6	47.7
7	20	3.6	58.9	8	5.3	53.0
8	19	3.0	61.9	13	4.0	57.0
9	2	2.4	64.3	26	3.6	60.6
10	3	2.4	66.7	2	3.2	63.8
11	7	2.4	69.1	19	3.2	67.0
12	15	2.4	71.5	6	3.1	70.1
13	26	2.4	73.9	25	2.8	72.9
14	16	1.8	75.7	3	2.5	75.4
15	24	1.8	77.5	4	2.5	77.9
16	28	1.8	79.3	16	2.0	79.9
17	9	1.2	80.5	7	2.0	81.9
18	12	1.2	81.7	17	2.0	83.9
19	21	1.2	82.9	10	1.9	85.8
20	6	.6	83.5	15	1.7	87.5
21	17	.6	84.1	20	1.5	89.0
22	22	.6	84.7	22	1.3	90.3
23	25	.6	85.3	21	1.1	91.4
24	27	.6	85.9	36	1.1	92.5
25	29	.6	86.5	27	.9	93.4

clear when the characteristics of the problem types are described in the following pages.

CLASS A PROBLEM TYPES

Table 33 lists the generic titles of the four Class A problem types, and shows the proportions of cases in the fatal and non-fatal samples that were classified into each problem type. The proportion of cases in the total class is shown at the bottom of the table.

All Class A accidents occurred at a mid-block location shortly after the bicyclist entered the roadway from a driveway, alley, or over a curb or shoulder. In almost every case, the bicyclist entered the roadway without slowing, stopping, or searching for oncoming traffic. Because of the bicyclist's suboptimal pre-crash course (path and/or speed), the motorist had insufficient time to avoid the accident once the bicyclist became visible and the bicyclist's intended path became apparent to the motorist. The function failures and contributing factors are similar for the four Class A problem types. The main differences among the problem types are the type of location at which the bicyclist entered the roadway, the factors that served to limit the operator's preview time,[14] and the bicyclist target group.

TABLE 33

PROBLEM CLASS A--BICYCLE RIDEOUT: DRIVEWAY, ALLEY, AND OTHER MID-BLOCK

		FATAL (N=166)	NON-FATAL (N=753)
TYPE 1	BICYCLE RIDEOUT: RESIDENTIAL DRIVEWAY/ALLEY, PRE-CRASH PATH PERPENDICULAR TO ROADWAY	6.7%	5.7%
TYPE 2	BICYCLE RIDEOUT: COMMERCIAL DRIVEWAY/ALLEY, PRE-CRASH PATH PERPENDICULAR TO ROADWAY	2.4%	3.2%
TYPE 3	BICYCLE RIDEOUT: DRIVEWAY/ALLEY APRON, PRE-CRASH PATH PARALLEL TO ROADWAY	2.4%	2.5%
TYPE 4	BICYCLE RIDEOUT: ENTRY OVER SHOULDER/CURB	3.6%	2.5%
TOTAL CLASS (N: FATAL = 25; NON-FATAL = 105)		15.1%	13.9%

[14]The term "preview time" is used here to refer to the time available between the point at which the operator first observed the other vehicle and the point at which the collision occurred.

PROBLEM-TYPE DESCRIPTIONS

Problem Type 1 (6.7% Fatal; 5.7% Non-Fatal)

Figure 26 illustrates the traffic context and critical actions for Problem Type 1. Accidents of this type occur when the bicyclist rides straight out of a residential driveway or alley and collides with a motor vehicle approaching from the left or right. Figure 26 shows that 72% of the collisions occurred in the first half of the roadway (the half nearest the point at which the bicyclist entered the roadway); the remaining 28% occurred in the second half of the roadway.

Problem Type 1 includes only the bicycle rideout accidents that occurred at the junction of a roadway and a residential driveway (48%), a residential alley (33%), or a driveway serving a rural residence (19%). Seventy-nine percent of the cases occurred on a two-lane[15] urban street

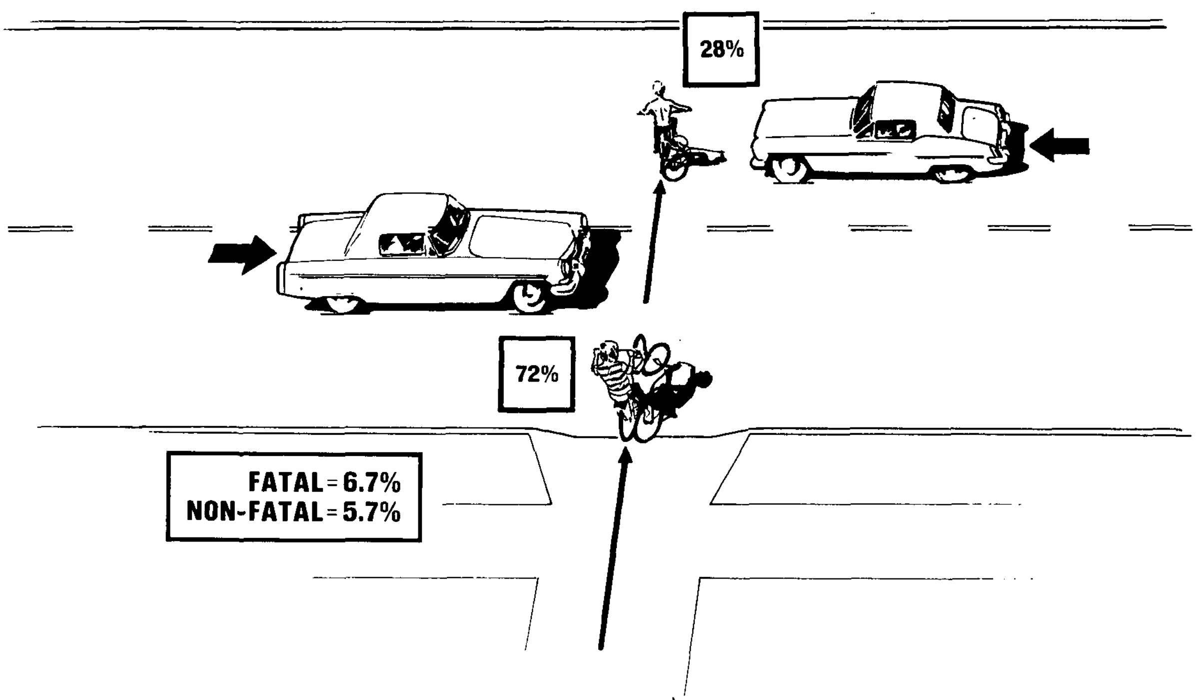

Figure 26. Illustration of Problem Type 1, *Bicycle Rideout: Residential Driveway/Alley, Pre-Crash Path Perpendicular to Roadway*.

[15]Unless stated otherwise, all the roadways referred to throughout this section are two-way roadways.

with light traffic and a posted speed limit of 25 MPH or less; 19% occurred on a two-lane rural roadway; and two percent occurred on an urban street with more than two lanes. Accidents of this type occurred almost exclusively during daytime hours, and the frequency of occurrence was greatest in the afternoon; 95% of the cases occurred during the daytime and 84% occurred between 2:00 PM and 7:00 PM.

A visual obstruction was a contributing factor in 63% of the accidents; parked motor vehicles and vegetation were the most common types of obstructing objects. When the operators' views were not obstructed, the accident was usually the result of one or both operators' failure to search in the direction of the other vehicle until an accident was imminent. In about nine percent of the cases, the motorist observed the bicyclist early enough to have avoided the accident, but proceeded with the assumption that the bicyclist would slow or stop before entering the roadway.

The motorist's failure to search in the bicyclist's direction was usually due to his expectation that all traffic entering the roadway from intersecting driveways and alleys would yield the right of way. In short, the motorist did not search in the bicyclist's direction because he saw no necessity to do so in that traffic context. The factors that contributed to the bicyclist's failure to search are more numerous and complex. The most common contributing factors revealed by the interviews include:

- Distracted by riding companion or pedestrian (26%),
- Distracted by play activity (19%),
- Distracted by factors other than play or interaction with another person (16%),
- Assumed area would be void of traffic (19%), and
- Assumed riding companion would search (13%).

Accidents of this type nearly always occurred close to the bicyclist's home; many occurred as the bicyclist was exiting the driveway serving his own residence. Consequently, most bicyclists were thoroughly familiar with the physical and operational characteristics of the accident location. Mainly because of his familiarity with the area, the bicyclist did not consider either the environment or his actions to be particularly hazardous. Therefore, risk *assessment* rather than risk *acceptance* must be considered an important factor for Problem Type 1. Although the bicyclists' actions would be perceived as risk-taking behavior by adults, it would be misleading to suggest that the bicyclists who were involved in this type of accident were any more willing to engage in risk-taking activities than the general population of bicyclists in the same age group.

Problem Type 1 involved bicyclists who were younger than those involved in any other problem type. The median age of the bicyclists was 9.8 years, and about five percent were five years of age or younger. Fewer than five percent of the bicyclists were 16 years of age or older.

Problem Type 2 (2.4% Fatal; 3.2% Non-Fatal)

As is shown in Figure 27, Problem Type 2 occurred in much the same way as Problem Type 1. The distinguishing characteristic of Problem Type 2 is that all the collisions occurred at the junction of a roadway and a *commercial* driveway (75%) or alley (25%). That is, the bicyclist rode *straight out* of a commercial driveway or alley into the approaching motor vehicle's path.

The accidents occurred with about equal frequency on two-lane urban streets (54%) and urban streets with more than two lanes (42%). But, in either case, the roadway was usually carrying moderate to heavy traffic at the time the accident occurred. Accidents of this type nearly always occurred during the daytime (96%) and the frequency was clearly greatest between 2:00 PM and 5:00 PM (58.4%).

In 39% of the cases, the motorist's preview time was critically limited by a visual obstruction. Parked motor vehicles, fences, and walls were the most common types of visual obstructions. The remaining 61% of the cases occurred even though the visibility conditions were good and the operators had a clear view of the other vehicle long before the collision occurred. About eight percent of the motorists observed the bicyclist in time enough to have avoided the accident but incorrectly assumed that the bicyclist would stop or turn at the junction. In about 42% of the cases, however, *the motorist failed to search in the direction of the clearly*

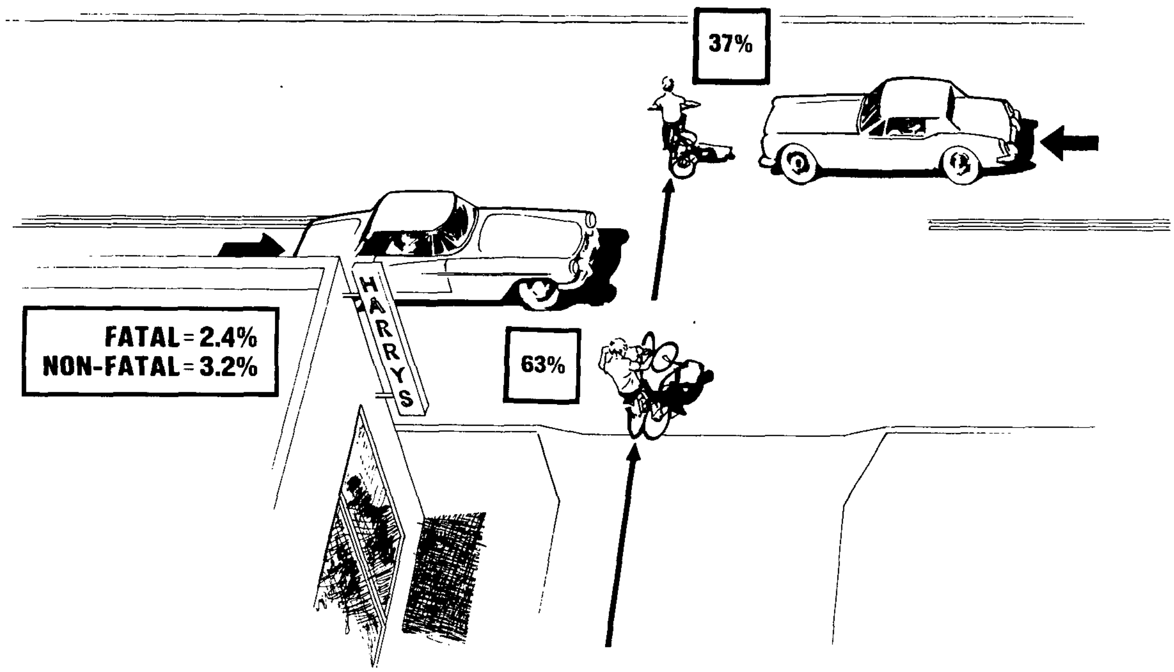

Figure 27. Illustration of Problem Type 2, *Bicycle Rideout: Commercial Driveway/Alley, Pre-Crash Path Perpendicular to Roadway.*

(NOTE: The building was drawn in the above illustration to indicate that this type of accident occurs at the junction of a *commercial* rather than a residential driveway/alley. Although a building sometimes obstructed the operator's view in accidents of this type, buildings were not the most frequent type of obstructing object.)

visible bicyclist because he assumed that all traffic entering the roadway from intersecting driveways would yield to him.

The bicyclist's suboptimal course and his failure to search were the result of a wide range of different factors. The most common are listed below.

- Distracted by play activity (23%),
- Distracted by riding companion (23%),
- Competing needs--need to catch up with riding companion (15%), and
- Competing needs--need for excitement generated by high speed (15%).

There were few cases in which the presence of information overload could clearly be established from the interview data. That is, few bicyclists believed that their information processing capacity was severely taxed by the information processing requirements that existed at the time of the accident. Even so, the authors believe that it is probable that a substantial portion of the bicyclists were heavily loaded (if not overloaded) by the task of entering a heavily trafficked, multiple-lane roadway, and that information overload or attentional conflict often contributed to the bicyclist's search failure.

Although the bicyclists involved in Type 2 accidents were usually juveniles, there was a substantial number who were in their late teens or older. The median age of the bicyclists for this problem type was 13.8 years; five percent of the bicyclists were seven years of age or younger, and five percent were 25 years of age or older.

Problem Type 3 (2.4% Fatal; 2.5% Non-Fatal)

Problem Type 3 is similar in many respects to Problem Types 1 and 2. As is illustrated in Figure 28, the distinguishing characteristic of Problem Type 3 is that the bicyclist entered the roadway from a *parallel sidewalk* by way of a *driveway apron*. About three-fourths of the collisions occurred in the near lane(s) and one-fourth occurred in the far lane(s).

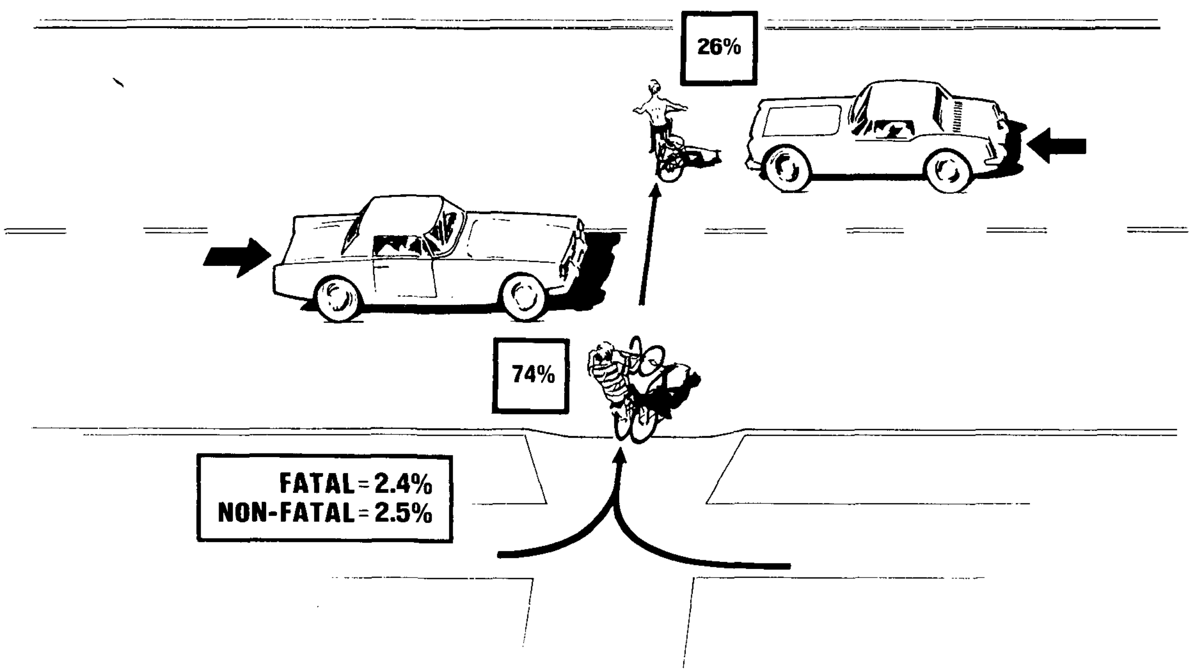

Figure 28. Illustration of Problem Type 3, *Bicycle Rideout: Driveway/ Alley, Pre-Crash Path Parallel to Roadway.*

Problem Type 3 includes accident cases that occurred at either a residential or a commercial driveway, but most accidents (89%) occurred at a residential driveway. (In this respect, Problem Type 3 is most similar to Problem Type 1.) Eighty-four percent of the collisions occurred on a two-lane residential street; the remaining 16% occurred on a roadway with more than two lanes. Eighty-nine percent of the accidents occurred during the day-time; 63% occurred between 2:00 PM and 7:00 PM.

Like the previous two problem types, there were many cases (47%) in which the bicyclist's pre-crash course combined with visual obstructions to limit the motorist's preview time to such an extent that there was no chance to avoid the accident once the bicyclist emerged from behind the obstructing object. In 22% of the cases, however, the motorist observed the bicyclist early enough to have avoided the accident, but incorrectly assumed that the bicyclist would continue riding on the sidewalk. In 17% of the cases, the bicyclist was visible, but the motorist failed to search in his direction because he assumed that all intersecting traffic would yield to him.

Even when visual obstructions were present, there were many instances in which the bicyclist could have observed the motor vehicle early enough to have avoided the accident. Thus, search failures accounted for 72% of the bicyclist's precipitating function failures. Most of the bicyclists' search failures were due to the presence of some type of distractor. The most frequent distractors were interacting with another person (36%), play activity (27%), and non-traffic-related mental activity (18%). In 18% of the cases, the bicyclist failed to search because he incorrectly assumed that a riding companion would search for hazards and select a safe course through the accident area.

The bicyclists who were involved in Type 3 accidents were slightly older than those involved in Type 1 accidents, but were younger than those involved in Type 2 accidents. For Problem Type 3, the median age of the bicyclists was 11.5 years. About five percent of the bicyclists were five years of age or younger, and about five percent were 16 years of age or older.

Problem Type 4 (3.6% Fatal; 2.5% Non-Fatal)

All Type 4 accidents occurred shortly after a bicyclist entered the roadway over a curb (74%) or shoulder (26%) at a mid-block location. Thirty-seven percent of the bicyclists stopped or slowed before entering the roadway; the remaining bicyclists made no attempt to slow their speed. As is shown in Figure 29, the bicyclist's pre-crash path was sometimes parallel to the roadway (42%) and sometimes perpendicular to it (58%). This type of accident most often occurred on a two-lane urban street (74%), but occasionally occurred on an urban street with more than two lanes (10%) or on a rural roadway (16%). Ninety-five percent of the accidents occurred during the daytime; 68% occurred between 3:00 PM and 6:00 PM.

The motorist's preview time was critically limited by visual obstructions in 41% of the cases: a parked motor vehicle was the most common type of visual obstruction. In 32% of the cases, the motorist observed the bicyclist well in advance and could easily have avoided the accident had he known that the bicyclist would enter the roadway. In the remaining 21%

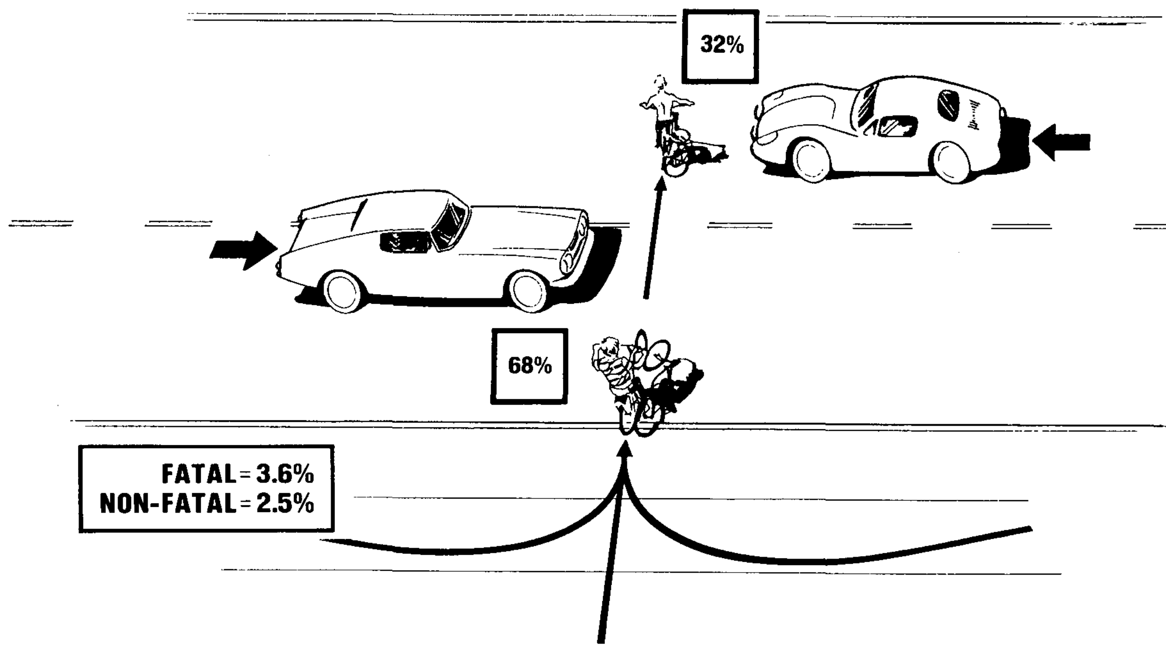

Figure 29. Illustration of Problem Type 4, *Bicycle Rideout: Entry Over Shoulder/Curb.*

of the cases, the motorist failed to search in the bicyclist's direction and therefore failed to observe the bicyclist (clearly visible) until it was too late to avoid the accident.

The objects that obstructed the motorist's view also obstructed the bicyclist's view in many instances (26%); but in the majority of cases, the bicyclist made no attempt to search in the motorist's direction before entering the roadway (53%). Of the factors that were found to contribute to the bicyclists' function failures, 67% were found to be distractions of one type or another. A wide range of distractors were revealed by the data, but there was no single type of distractor that was clearly more important than any other. Surprisingly, there were few bicyclists who reported that they were distracted by the act of riding over the curb or shoulder. It seems almost certain that most bicyclists' attention would be focused on the curb/shoulder they are preparing to ride over: the closer the bicyclist's position to the curb/shoulder, the more his scan would be directed downward. Thus, although not directly supported by the data, it seems reasonable to assume that the bicyclist's failure to search was often due, in part, to the distractions inherent in the act of riding over a curb or shoulder.

COUNTERMEASURE APPROACHES FOR CLASS A PROBLEM TYPES

Environmental Changes

Removal of visual obstructions. Visual obstructions were an important contributing factor for all four problem types within Class A. It follows that the removal of obstructing objects at the target locations has the potential for decreasing the incidence of Class A accidents. Most readers will recognize that the widespread removal of visual obstructions would be costly and politically difficult to accomplish. However, these facts do not warrant the immediate dismissal of this countermeasure approach.

Parallel-parked motor vehicles were the most frequent obstructing object for all four problem types within Class A. For Problem Types 1 through 3, the motor vehicle(s) that obstructed the operator's view was parked close to a residential or commercial driveway/alley junction. Therefore, prohibition of parking within a fixed distance of driveway/alley junctions would have a direct impact on three of the four problem types. The data indicate that the removal of parked motor vehicles in close proximity to driveway/alley junctions has the potential for eliminating about 25% of the Class A accidents and about four percent of *all* bicycle/motor-vehicle accidents. The minimum size of the restricted parking area surrounding a driveway/alley junction could be derived analytically by considering such factors as the operating speed for the roadway, the distance between the curb and the traffic lane, the coefficient of friction for the roadway, and the motorists' reaction times.

Since bicyclists can enter the roadway over a curb or shoulder at virtually any location, parking restrictions that would be effective in reducing Problem Type 4 accidents would require the prohibition of all on-street parking. Because the relative frequency of this problem type is low and because the elimination of all on-street parking would be totally impractical, it appears that other approaches must be used to counter accidents of this type. For instance, diagonal parking, as opposed to parallel parking, would discourage bicyclists from entering the roadway over a curb in areas where all parking spaces are filled most of the time. That is, bicyclists would find it difficult to enter the roadway between two diagonally parked motor vehicles without slowing to a very slow speed.

If this countermeasure approach is to be fully effective, it would also be necessary to remove or modify objects other than parked motor vehicles. Vegetation, embankments, walls/fences, and buildings that obstruct motorists' views of driveway and alley approaches would have to be removed or modified. The removal or trimming of vegetation would be a relatively simple matter and could probably be accomplished under the authority of existing local ordinances. The removal of vegetation that obstructs vision has the potential for eliminating about 12% of the Class A accidents and about two percent of *all* bicycle/motor-vehicle accidents.

The removal of embankments and structures would be far more difficult. Although it may be impractical to remove existing embankments and structures, it would be possible to establish design standards that would prevent such obstructions in all new construction. When obstructing objects cannot be removed or modified, the next best alternative would be to install signs to warn operators that they are approaching a blind junction. Special mirrors that enhance the operator's view at blind junctions might prove effective at locations that are severely hazardous.

When assessing the potential gains that would be achieved from the removal of visual obstructions, it must be kept in mind that more than one-half of the Class A accidents occurred at locations where no visual obstructions were present. Thus, without countermeasures to increase both operators' inclination to search effectively, it is unlikely that Class A accidents would be reduced in direct proportion to the number of visual obstructions removed.

Roadway designs to modify the operator's pre-crash course. One potentially effective countermeasure approach for Class A accidents is to modify the physical characteristics of the travelway (roadway, driveway, sidewalk, etc.) in a manner that would effect a desired change in the operator's pre-crash course. The objective of such changes would be to modify one or both operator's pre-crash course in a manner that would serve to increase the operator's preview time once the other vehicle becomes observable. While it appears that greater gains would be achieved from modifying the bicyclist's pre-crash course, techniques to modify the motorist's course cannot be ignored.

It seems reasonable to assume that accident likelihood for Class A accidents would be reduced by physical changes that would cause the bicyclist to reduce his speed upon entering the roadway or cause him to enter the roadway at a more beneficial angle. Such changes might be achieved by one or a combination of the following techniques:

- Install removable barriers (gates, cables, etc.) or permanent speed control "bumps" or baffles that would extend across residential driveway approaches. Such devices would be installed on private property and would be designed such that bicyclists would not or could not ride over or around them without reducing their speed substantially. Since Type 1 accidents often occurred as the bicyclist was exiting the driveway of his own residence, these devices may prove cost effective if installed only by parents of the young bicyclists who constitute the target group for Problem Type 1.

- Install speed-control "bumps" or baffles across sidewalks at locations where sidewalks intersect driveways or alleys. The purpose of such devices would be to reduce the speed of bicyclists who may turn suddenly from the sidewalk and enter the roadway by way of a driveway/alley apron (Problem Type 3). The main difficulty with this approach is the development of devices that would cause bicyclists to reduce their speed but would not create a safety hazard for pedestrians.

- Install speed-control "bumps" or baffles across driveway/alley aprons at a location close to the roadway. Such devices would have an impact on all Class A accidents except those in which the bicyclist enters the roadway over a curb or shoulder (Problem Type 4). Devices of this type have the potential for eliminating 82% of the Class A accidents and at least 11% of all bicycle/motor-vehicle accidents. The authors believe that this approach has a greater potential for reducing Class A accidents than any other physical change discussed here.

- Barriers that would prevent bicyclists from entering the roadway at points other than driveways or alleys would be effective for Problem Type 4 accidents, but would be excessively expensive considering the infrequency with which accidents of this type occur. For new roadways, it may be possible to develop curb designs that bicyclists would not, or could not, ride over without reducing their speeds substantially.

- Develop driveway entrances that would force the bicyclist to enter the roadway at an oblique angle, facing traffic approaching in the near traffic lane. This approach would direct the bicyclists gaze at motor vehicles approaching in the nearest traffic lane and, if the bicyclist continued into the roadway at an oblique angle, would increase slightly the distance the bicyclist would travel prior to intersecting the motorist's path. An obvious problem with this approach is that an oblique driveway entrance would be inconvenient for motor vehicles. In addition, if an accident should occur, the oblique entry would result in a somewhat greater impact velocity than a perpendicular entry.

If preview time is to be increased by modifying the *motorist's* precrash course, it would be necessary to reduce the speed of the motor vehicle, increase the distance between the motor-vehicle's path and the edge of the roadway, or both. Although most Class A accidents occur in areas where the speed limit already is low, a further reduction in the posted speed limit for selected target areas might be acceptable to roadway users. Another approach to modifying the motorist's pre-crash course would involve the development of techniques for inducing the motorist to slow his speed only at "blind" junctions. This might be achieved with special pavement markings that would alert the motorist that he is approaching a blind driveway/alley junction. To alert motorists that they are approaching a junction that may be obscured by parked motor vehicles, it would be necessary to mark nearly every driveway/alley junction. Although marking every "potentially blind" driveway/alley junction may not prove cost effective, it may be feasible to mark all junctions that are obscured by a permanent object that cannot easily be removed or modified.

A complementary technique would involve defining the boundary of travel lanes in a manner that would provide the largest possible "buffer zone" between the traffic lane and the nearest curb. On wide streets, it would be possible to use painted stripes to define the right-hand edge of the traffic lane such that traffic would be forced as far to the center of the roadway as is possible without creating a safety hazard. On narrow streets, a single lane could be defined in the center of the roadway which would be used by vehicles traveling in both directions except when approaching vehicles must pass one another. The latter solution would be most effective on one-way streets.

Most persons evaluate on-street bicycle lanes in terms of their potential for eliminating accidents in which a motor vehicle overtakes and collides with a slower-moving bicycle traveling in the same direction. However, a greater benefit of on-street bicycle lanes may be their provision of a buffer zone of the type discussed above. Whereas on-street bicycle lanes may not have a significant impact on overtaking accidents (Class D), they could have a large impact on all "mid-block rideout" accidents (Class A) and some "intersection rideout" accidents as well (Class B).

Bicycle Modifications

A study of the problem types within Class A clearly indicates the need for two types of bicycle modifications. First, a method is needed to increase the vertical dimension of the bicycle-bicyclist unit such that a reasonably large and clearly visible portion of the unit would appear above parked motor vehicles and other low-lying visual obstructions. The safety flags presently on the market appear to have potential utility for this purpose, but no information is available concerning their effectiveness. Some expert bicyclists believe that the size of the flag and supporting antenna are so small that they would seldom be observed by motorists even though they are higher in elevation than intervening obstructions. The effectiveness of safety flags probably could be improved if they were augmented with a small mutli-directional strobe light mounted on the tip of the antenna. Adult bicycling enthusiasts would be reluctant to use safety flags because of the weight, the extra drag, the noise, and the inconvenience they create when mounting and dismounting. However, it is believed that the juvenile bicyclists who typically are involved in Class A accidents would not be strongly opposed to a safety flag mounted on their bicycle.

A second requirement is to increase the daytime conspicuity of the bicycle-bicyclist unit. As the term is used here, conspicuity refers to the "attention-getting quality" of the bicycle-bicyclist unit--particularly when the unit appears in the motorist's peripheral field of view. Since color cannot be discriminated when an object is viewed peripherally, it appears that brightness contrast, movement, and size are the parameters that must be manipulated in order to increase bicycle conspicuity.

The authors have been unable to define a simple and inexpensive technique that they are confident would (a) increase conspicuity, and (b) always be present on the bicycle or bicyclist. Bright clothing does not appear to be a potentially effective technique, because it would be difficult to induce young bicyclists to always don a special type of clothing each time they chose to ride their bicycles. Painting the bicycle a bright color would have little effect because of its small size; and increasing the size of the bicycle does not seem feasible. A powerful multi-directional strobe light should prove effective in attracting motorists' attention. However, such a defice undoubtedly would be costly and difficult to maintain, considering the manner in which many juvenile bicyclists use their bicycles. Nevertheless, the cost may be more than offset by the benefits in reducing Class A accidents and other types of accidents which are discussed later.

Education and Training

It seems clear that the education and training of motorists and bicyclists would prove effective in reducing the incidence of all four problem types within Class A. However, it is also possible that educating and training could prove effective for the parents of juvenile bicyclists, law enforcement officers, and bicycle-design engineers. The objective of an education and training program for each of these groups is discussed briefly below.

Bicyclists. If education and training of bicyclists is to be effective in reducing Class A accidents, it must be administered at a very early age--preferably in kindergarten and certainly not later than the fourth grade. For instance, consider the age of the bicyclist for Problem Type 1. The data showed that more than five percent of the Type 1 accidents involved bicyclists who were five years of age or younger, and 25% of the cases involved bicyclists who were younger than eight years of age. The age of the 5th and 25th centile bicyclist for the other three Class A problem types is only one or two years older than for Problem Type 1. Clearly, the requirement to impart, to very young children, the knowledge and skills necessary to avoid Class A accidents represents a formidable task.

There were very few instances in which a bicyclist rode into a motor vehicle's path because he misjudged the motor vehicle's approach velocity. Therefore, it seems reasonable to assume that most Class A accidents would be avoided if the bicyclist could be taught to stop at the edge of the roadway and search carefully for oncoming motor vehicles. In fact, substantial gains would probably be achieved if the bicyclist could merely be induced to stop at the junction or slow his speed considerably, thereby giving the motorist sufficient time to observe the bicyclist and initiate evasive action. To counter Class A accidents, an ideal educational program for young bicyclists would accomplish at least the following:

- Modify bicyclists' assessment of the risk associated with entering *any* roadway at *any* mid-block location.
- Teach the bicyclist to search for and recognize all types of visual obstructions and the exact behavioral sequence to follow when obstructing objects are present.
- Teach the bicyclist the importance of momentary distractions and how to cope with them.
- Teach the bicyclist the proper behavioral sequence when entering the roadway when visual obstructions are *not* present.

Motorists. This study revealed no indication that the motorists who were involved in Class A accidents were atypical in their skills or their concern for safety. Even so, it is possible that some accidents of this type could be avoided if the general motoring public was informed of the frequency with which Class A accidents occur, where they occur, and the reasons for which they occur. The main objectives of an education and training program for the general motoring public would be to:

- Modify motorists' search patterns in a manner that would increase the likelihood of detecting bicyclists who were riding on the sidewalk or in intersecting driveways.
- Modify motorists' expectations about bicyclists emerging from behind visual obstructions suddenly and without warning.
- Induce motorists to modify their speed and path through high-hazard areas.

Bicyclists' parents. The education of parents of bicyclists in the target group could result in parents assuming more responsibility for the bicyclists' training and, more importantly, a greater degree of parental control of where and how young bicyclists are permitted to ride. Casual observation indicates that most parents generally recognize that riding a bicycle may be dangerous for very young children, but few parents appear to have a clear understanding of the types of locations where bicycle/motor-vehicle accidents occur or the types of bicyclist actions that most often lead to such accidents. It is altogether possible that misinformed parents may be giving their children instructions that are counterproductive. For instance, the instruction to "ride close to home" may cause the bicyclist to ride in an area that is less safe than available alternative areas.

The main objective of a parent-education program is to inform parents of the frequency with which Class A accidents occur, how they occur, and why they occur. If parents are to be effective in educating their children, they must have a clear understanding of the function failures and contributing factors that lead to an accident. It is particularly important that parents understand that quiet neighborhood streets and thorough familiarity with the area do not ensure the bicyclist's safety.

Law enforcement officers. Educating patrol officers about the importance of Class A accidents and the reasons for which they occur could prove useful in curtailing the behavior that leads to these types of accidents. That is, an understanding that many bicycle/motor-vehicle accidents occur as the bicyclist enters the roadway would increase the likelihood that an officer would observe and issue citations to bicyclists who enter the roadway in an unsafe manner. However, an education and training program for law enforcement officers must be preceded by the passage of ordinances that make unsafe entry into the roadway unlawful.

Bicycle designers. A first step in the development of methods to increase the vertical dimension and conspicuity of bicycles would be to educate bicycle-design engineers about the need for such devices. Thus, persons who are involved directly or indirectly with bicycle design should be educated on the importance of Class A accidents and the nature of the accident-generation process for these types of accidents.

Regulations and Enforcement

Selective prohibition. One sure way of reducing the incidence of Class A accidents is to prohibit bicyclists from riding on public streets until they reach a certain age and/or have participated in an effective bicycle-safety education program. About one-half of the bicyclists who were involved in Class A accidents were ten years of age or younger. It seems reasonable to assume that many Class A accidents would not occur if bicyclists younger than ten or eleven years of age were prohibited from riding a bicycle on public streets. The "Catch-22" implications of this recommendation are recognized; that is, bicyclists cannot ride on public streets until they are experienced, and they cannot gain the required experience until they have the opportunity to ride on public streets. However, it can be convincingly argued that the knowledge and skills required to avoid Class A accidents would be acquired with very little training once the bicyclist has reached a certain maturation level.

Traffic regulations. In most states (perhaps all of them), the law states that a vehicle operator must yield the right of way when entering the roadway from a driveway or alley. However, as presently written, the law does not require a bicyclist to stop or even slow to a reasonable speed unless another vehicle will be affected by his actions. In short, the bicyclist has not violated the law when he enters the roadway without slowing or stopping unless his actions result in an accident or near accident. As a consequence, an enforcement officer has no firm legal basis for issuing a citation to a bicyclist who enters the roadway unsafely when no motor vehicles are nearby. It appears impossible to establish an enforcement program that would be effective in reducing Class A accidents until a law or ordinance is passed that makes it unlawful to enter a roadway without stopping or slowing.

Additional study will be required to determine whether or not regulations should require *all* bicyclists to come to a complete stop before entering the roadway under *all* circumstances. Certainly, experienced adult bicyclists would be strongly opposed to a regulation requiring them to always come to a complete stop before entering a roadway at a mid-block location.

Ordinances for removal of visual obstructions. If progress is to be made in the removal of visual obstructions that contribute to Class A accidents, it will be necessary to establish effective and reasonable ordinances concerning the removal of visual obstructions; and it will be necessary to develop a program that will ensure the enforcement of these regulations. Regulations concerning visual obstructions already exist in most communities, but are seldom enforced.

CLASS B PROBLEM TYPES

Table 34 lists the problem types within Class B and shows the relative frequency with which they occurred. The distinguishing characteristic of all Class B problem types is that the bicyclist entered a controlled intersection in an unsafe and usually unlawful manner. In all Class B accidents, the motorist and bicyclist were traveling on orthogonal legs of the intersection. Problem Type 5 includes accidents that occurred at an intersection controlled by a "stop" or "yield" sign; Problem Types 6 and 7 occurred at a signalized intersection. All accidents classified as "Other Class B" also occurred at a signalized intersection, but these accidents differed in important respects from the accidents that were classified into Problem Types 6 and 7.

TABLE 34

PROBLEM CLASS B--BICYCLE RIDEOUT: CONTROLLED INTERSECTION

		FATAL (N=166)	NON-FATAL (N=753)
TYPE 5	BICYCLE RIDEOUT: INTERSECTION CONTROLLED BY SIGN	7.8%	10.2%
TYPE 6	BICYCLE RIDEOUT: INTERSECTION CONTROLLED BY SIGNAL, SIGNAL PHASE CHANGE	.6%	3.1%
TYPE 7	BICYCLE RIDEOUT: INTERSECTION CONTROLLED BY SIGNAL, MULTIPLE THREAT	2.4%	2.0%
OTHER CLASS B	BICYCLE RIDEOUT: INTERSECTION CONTROLLED BY SIGNAL, OTHER	1.2%	1.7%
TOTAL CLASS (N: FATAL = 20; NON-FATAL = 128)		12.0%	17.0%

PROBLEM-TYPE DESCRIPTIONS

Problem Type 5 (7.8% Fatal; 10.2% Non-Fatal)

Problem Type 5 includes "bicycle rideout" accidents that occurred at a signed intersection. The approach leg traveled by the bicyclist was controlled by a "stop" sign in 96% of the cases and a "yield" sign in only four percent of the cases. The approach leg on which the motorist was traveling was uncontrolled, except for three percent of the cases which occurred at an intersection controlled by a four-way stop sign. Eighty-two percent of the bicyclists entered the intersection without slowing or stopping; 18% slowed significantly or stopped at the intersection before riding into the path of the oncoming motor vehicle. More will be said later about the bicyclist's speed control upon entering the intersection. About six percent of the motorists were traveling at a speed that exceeded the posted limit; but, in the remaining cases, the motorist's speed was judged to be well within the normal range.

Seventy-five percent of the cases occurred at the junction of a pair of two-lane streets. In 17% of the cases, the motorist was traveling on a four-lane street and the bicyclist was traveling on a two-lane street. The remaining cases occurred at the junction of a pair of four-lane streets (4%) or at the junction of a pair of two-lane rural roadways (4%). Most accidents occurred during the daytime (94%), and they occurred with about the same frequency throughout the period between 7:00 AM and 7:00 PM.

Figure 30 shows that 22% of the bicyclists were riding facing traffic prior to the accident. Riding facing traffic was an important contributing factor because it decreased the likelihood that the bicyclist would be detected by the motorist in this situation. But, the most critical factor was the bicyclist's failure to slow or stop at the junction. That is, riding facing traffic contributed to the accident only because the bicyclist failed to stop at the junction.

It can be seen in Figure 30 that almost two-thirds of the collisions occurred before the bicyclist reached the center of the roadway. This finding can be attributed to the fact that motorists approaching from the

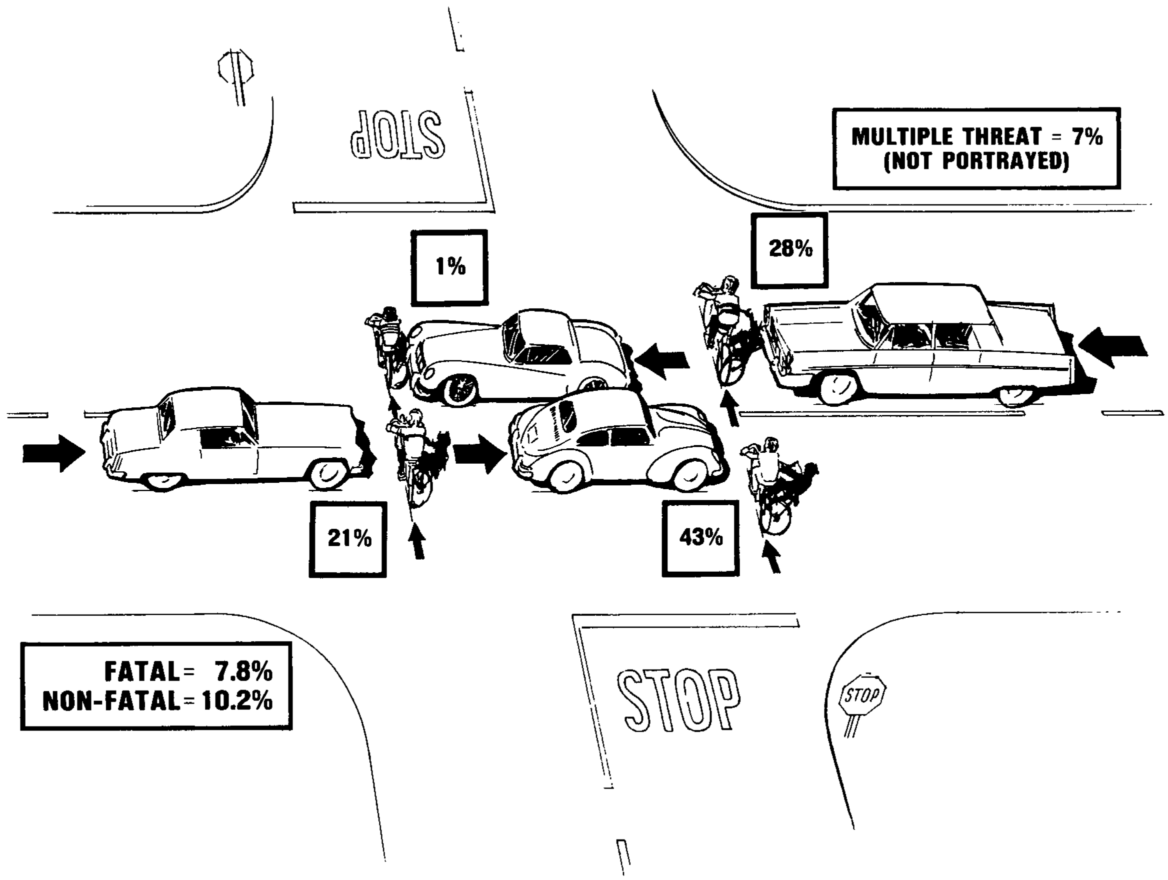

Figure 30. Illustration of Problem Type 5, *Bicycle Rideout: Intersection Controlled by Sign.*

left, in the near traffic lane(s), have very little time to initiate evasive action once it becomes apparent that the bicyclist does not intend to stop. Motorists approaching from the right have more time to respond because the bicyclist must travel across an entire traffic lane before he intersects the motor vehicle's path.

Seven percent of the cases classified into Problem Type 5 were "multiple-threat" accidents--a variation of Problem Type 5 that is not portrayed in Figure 30. In these cases, a motorist observed the bicyclist and slowed or stopped to let him pass. The bicyclist observed the motorist slow or stop, assumed it was safe to cross the roadway, and proceeded into the intersection where he collided with a second motor vehicle. Every case of this type occurred in California where motorists are accustomed to yielding the right of way to pedestrians. Apparently, the motorists in these cases treated the bicyclist as a pedestrian rather than as a vehicle operator.

The motorist's view of the bicyclist was obstructed in about 31% of the cases--usually by vegetation. It was surprising to find that parked motor vehicles obstructed the operator's view in only three percent of the cases. About five percent of the motorists failed to detect the approaching bicyclist because of darkness, inadequate bicycle lighting, or both. In all of the cases that involved obstructions or degraded visibility, it was judged that the motorist's preview time was critically limited and that the accident was imminent at the point at which the bicyclist could first have been observed/detected.

The motorist had sufficient preview time to have avoided the accident in the majority of cases. The motorist failed to search in the direction of the bicyclist (clearly visible) in about 40% of the cases. The motorist's search failure was usually because he assumed that all intersecting traffic would yield the right of way to him, or because the bicyclist was riding in an unexpected location (wrong side of street). In 13% of the cases, the motorist observed the bicyclist soon enough to have avoided the accident, but failed to initiate evasive action because he assumed the bicyclist would slow, stop, or turn at the intersection.

The bicyclist's speed control at the intersection is a critical factor in explaining his role in Type 5 accidents. The classification of cases in terms of the bicyclist's speed control at the junction revealed the following variations or subtypes for Problem Type 5:

- Bicyclist stopped and concluded it was safe to proceed (13%)
  --Multiple threat (7%)
  --Other (6%)
- Bicyclist slowed significantly and concluded it was safe to proceed (5%)
- Bicyclist failed to slow (82%)
  --Attempted to stop but could not (7.8%)
  --No attempt to slow or stop (74%)

The bicyclist's function failures are discussed for each of these variations of Problem Type 5.

First consider the accidents in which the bicyclist stopped at the junction and concluded that it was safe to proceed (13%). More than half of these accidents were multiple-threat accidents (described above); the remainder involved a bicyclist who failed to search properly (3%) or who misjudged the motor-vehicle's approach speed (3%). Next, consider the cases in which the bicyclist slowed significantly and concluded it was safe to proceed (5%). These accidents were due to the bicyclist's failure to search effectively or his failure to take into account the presence of visual obstructions.

Finally, consider the accidents in which the bicyclist clearly failed to slow his speed. In 7.8% of the cases, the bicyclist *attempted* to stop at the junction but was unable to do so because of a skill deficiency, defective brakes, wet caliper brakes, wet pavement, or a combination of these. The bicyclist in these cases misjudged his ability to manipulate the brakes or misjudged stopping distance under the conditions that existed at the time of the accident. In 74% of the cases, the bicyclist made *no attempt* to stop or slow prior to entering the intersection. The interview data clearly showed that the bicyclist's failure to stop or slow at the intersection was *not* the result of his failure to observe the stop sign. The accidents nearly always occurred at an intersection through which the bicyclist had ridden many times before the accident; so most bicyclists knew perfectly well that a sign was present at that location. Furthermore, it is clear that the bicyclist's failure to stop was not the result of ignorance of the law. Even the youngest bicyclist admitted knowing that the law requires bicyclists to stop for stop signs and to yield the right of way at intersections controlled by a yield sign. So, failure to observe traffic signs and ignorance of the law definitely are not important contributing factors for Problem Type 5.

Of the bicyclists who failed to slow or stop, it was judged that nearly 70% could have avoided the collision if they had searched in the direction of the motor vehicle prior to entering the intersection. In the remaining cases, because of the combined effects of the bicyclist's speed and an obstructed view, it was judged that the bicyclist could not have avoided the accident at the point where the motor vehicle first could have been observed. The bicyclist's failure to slow or stop and his failure to search must be explained in terms of the following factors:

- Operator distractions (41%)
  --*Interacting with riding companion or pedestrian (31%)*
  --*Play activity (3%)*
- Faulty expectations/assumptions (32%)
  --*Assumed area would be void of traffic (most cases probably)*
  --*Expected riding companion to select safe course (9%)*
- Competing needs (25%)
  --*Need to conserve time (14%)*
  --*Need for excitement generated by high speed (7%)*
- Information overload (17%)

Although a variety of factors contributed to the bicyclist's failure to stop at the intersection, it is the authors' opinion that faulty risk assessment was an overriding factor in most cases. This opinion is based upon three facts. First, most accidents occurred at a relatively safe-appearing intersection: in most cases, the operators were traveling residential roadways on which both traffic volume and operator speeds were low. Secondly, most accidents occurred at an intersection that the bicyclist had ridden through many times before the accident--probably without stopping in many instances. Third, the bicyclists' self-ratings provided no indication that their actions were due to a high willingness to accept risks. For these reasons, it seems reasonable to assume that the overriding reason for most bicyclists' failure to stop was their expectation that the roadway would be void of traffic. Although few bicyclists admitted to this fact during the interview, the authors believe that this was due partly to the bicyclist's reluctance to report such an unrealistic expectation and partly due to the Field Investigator's failure to probe on this matter.

Although bicyclists of all ages frequently fail to stop or slow at signed intersections, Type 5 accidents nearly always involved a juvenile bicyclist. The median age of the bicyclists involved in this type of accident was 11.8 years; less than 25% of the bicyclists were older than 14 years of age; about five percent of the bicyclists were older than 18 years of age.

Problem Type 6 (.6% Fatal; 3.1% Non-Fatal)

All accident cases classified into Problem Type 6 occurred at a signalized intersection. Eighty-three percent of the accidents occurred as the bicyclist was crossing an intersecting street with four or more traffic lanes. Although the majority of these accidents occurred during daytime, 17% occurred during darkness. About 70% of all Type 6 accidents occurred during the period between 1:00 PM and 7:00 PM.

The distinguishing characteristic of Problem Type 6 is that the bicyclist entered the intersection as the signal phase was changing and failed to clear the intersection before the signal turned red. In all cases, the motorist entered the intersection after the signal controlling his approach turned green. Problem Type 6 does not include cases in which the bicyclist entered the intersection more than one or two seconds after the onset of the red-signal phase. In addition, Problem Type 6 does not include "multiple-threat" accidents. Multiple-threat accidents were classified into Problem Type 7 and are described below. As is shown in Figure 31, 38% of the collisions occurred before the bicyclist reached the center of the roadway he was crossing; the remaining 62% occurred in the second half of the roadway the bicyclist was crossing.

In 78% of the cases, the motorist failed to search in the bicyclist's direction until it was too late to avoid the accident. In the remaining cases, the motorist either (a) searched adequately but failed to detect the bicyclist because of darkness, inadequate bicycle lighting, or both (4%); or (b) searched for and detected the bicyclist soon enough to have avoided the accident, but assumed the bicyclist would stop or slow before entering the motor vehicle's path (13%). The motorist's failure to search in the bicyclist's direction was due partly to his faulty assumption that all intersecting traffic would yield to him and partly to information overload. It is clear that the motorist's information processing capacity was heavily loaded by the requirement to watch the signal, search for pedestrian and vehicle traffic, control the speed and position of his vehicle, and so on.

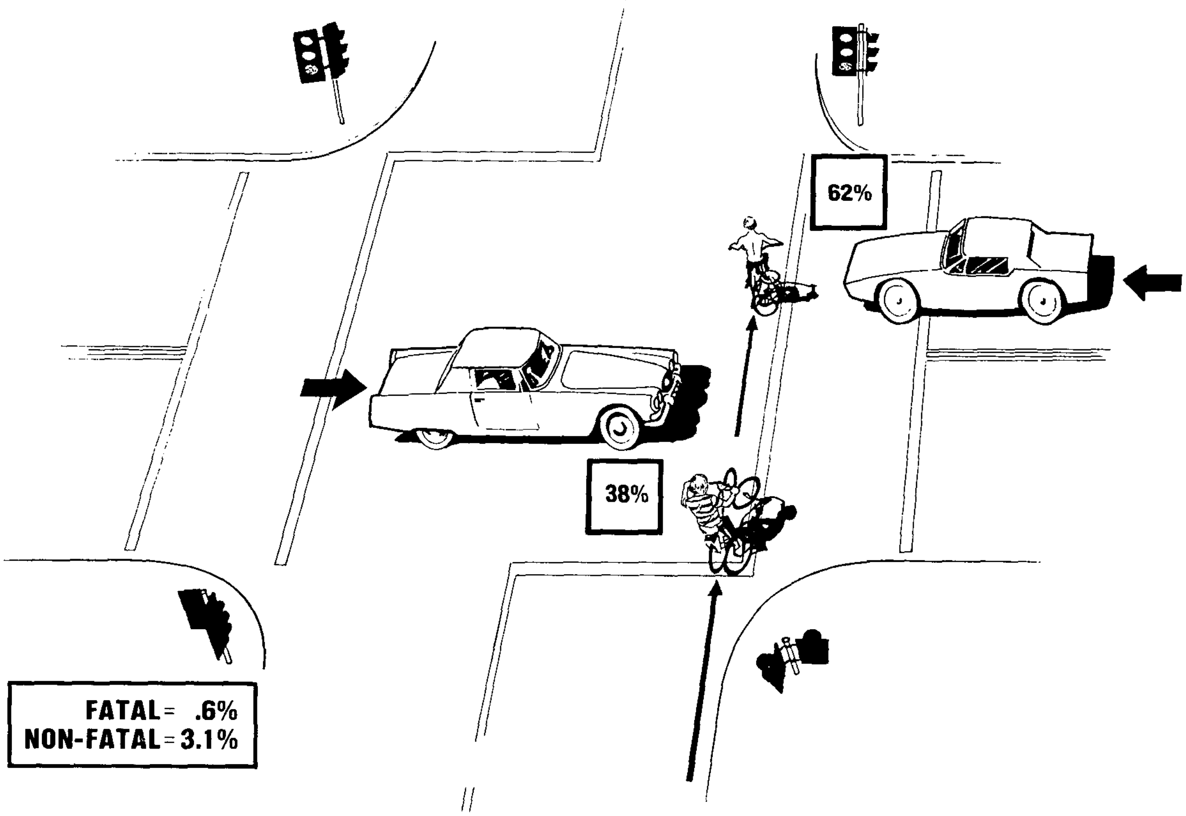

Figure 31. Illustration of Problem Type 6, *Bicycle Rideout: Intersection Controlled by Signal, Signal Phase Change.*

Nearly 57% of the bicyclists failed to search in the direction of the motor vehicle until an accident was imminent; 30% of the bicyclists observed the motor vehicle but assumed it would stop or remain stationary until the intersection was clear. Only four percent of the accidents were due to an action failure by the bicyclist. The evidence available for this problem type indicates that some bicyclists failed to stop at the intersection because they were unaware that the signal had changed since they last checked it. Other bicyclists knew that the signal had changed but assumed they could clear the intersection before the termination of the amber phase. However, because admitting to trying to beat the red light is more incriminating than admitting to a failure to notice the signal-phase change, it is not possible to estimate accurately the relative proportion of the bicyclists who made each type of error. However, it was found that 16% of the bicyclists were following a riding companion whom they assumed would search for hazards and select a safe course.

Because of the complexity of the traffic context and the usually high speed of the bicyclist, it is assumed that information overload contributed to the bicyclist's failure to carefully monitor the traffic signal, to search for approaching traffic, or both.

The relatively low incidence of fatal accidents for Problem Type 6 is due to the low motor-vehicle speeds at impact. Because the collision occurred as the signal phase was changing, the motorist was either accelerating from a stopped position or, more commonly, had slowed to a low speed for the red signal and accelerated when the signal turned green a moment before the collision.

About half the bicyclists involved in Type 6 accidents were juveniles, and half were young adults or adults. The median age of the bicyclists was 16.1 years; about 25% were 18 years of age or older. Only five precent of the bicyclists were younger than 11 years of age. As a group, the bicyclists involved in Type 6 accidents were considerably older than those involved in any of the problem types discussed previously.

Problem Type 7 (2.4% Fatal; 2.0% Non-Fatal)

Problem Type 7 is highly similar to Problem Type 6 with respect to target location, target period, and the nature of the bicyclist's pre-crash course. Problem Types 6 and 7 differ in one important respect. For Problem Type 7, the bicyclist's decision to proceed across the intersection was influenced by the presence of other motor vehicles that were stopped at the intersection, apparently waiting for the bicyclist to pass. The nature of the accident-generation process for Problem Type 7 is illustrated in Figure 32. It can be seen that 14% of the accidents occurred in the first half of the roadway and involved a bicyclist who was riding facing traffic. The remaining 86% of the cases occurred in the second half of the roadway and involved a bicyclist who was riding on the correct side of the street. In all cases, the bicyclist passed in front of one or more stopped vehicles before colliding with the accident vehicle.

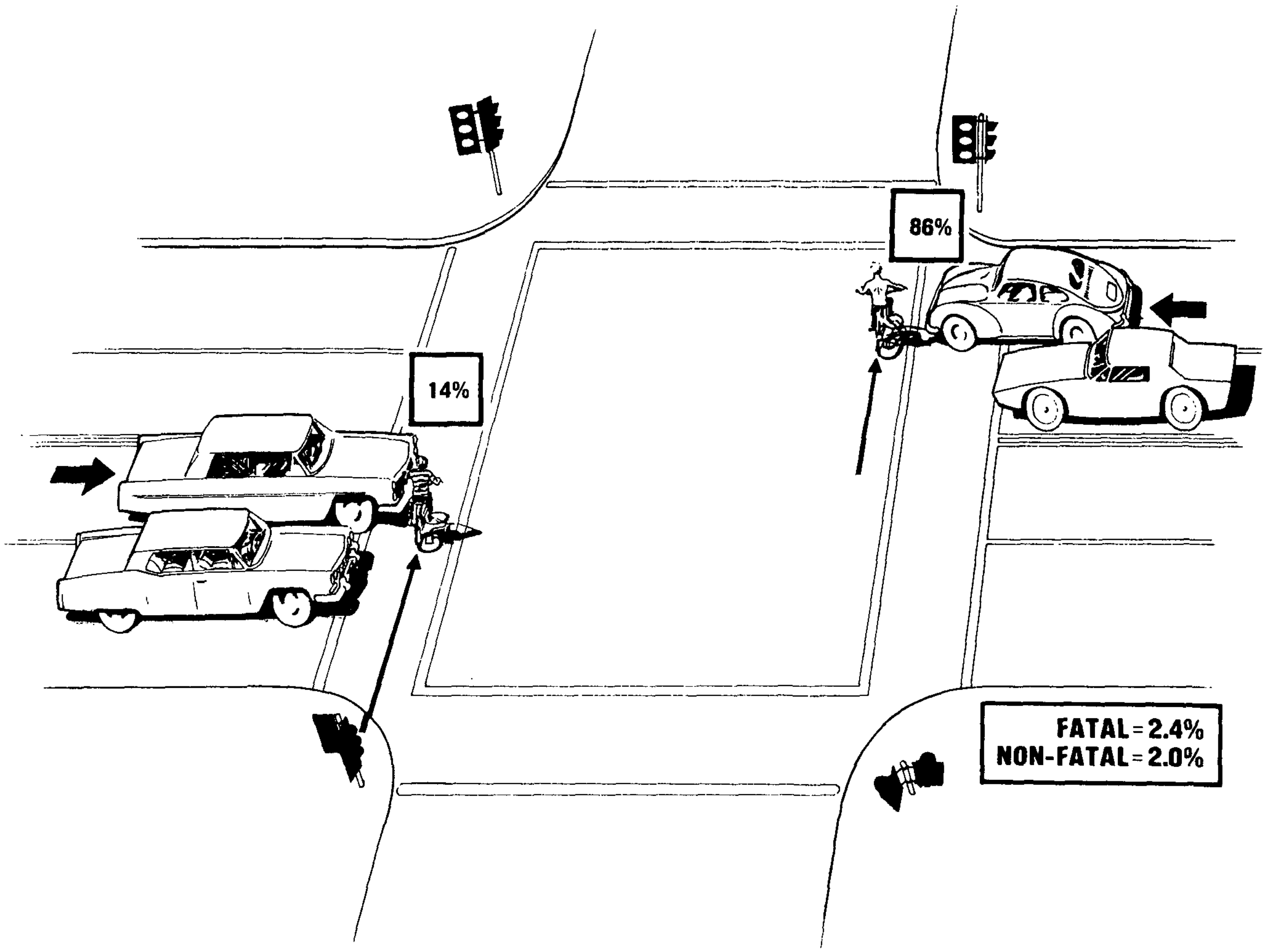

Figure 32. **Illustration of Problem Type 7,** *Bicycle Rideout: Intersection Controlled by Signal, Multiple Threat.*

Standing motor vehicle(s) obstructed the motorist's view of the bicyclist in 53% of the cases. In these cases, there was no chance for the motorist to initiate successful evasive action once the bicyclist emerged from behind the stopped vehicles. In 40% of the cases, it was judged that the motorist could have observed the approaching bicyclist, but he failed to search in the bicyclist's direction. In about seven percent of the cases, the motorist searched in the bicyclist's direction but failed to detect the bicyclist because of darkness, inadequate bicycle lighting, or both.

The standing motor vehicle(s) obstructed the bicyclist's view of the approaching motor vehicle in nearly 27% of the cases. Given the speed the bicyclist was traveling prior to the collision, it was judged that there was insufficient time to have avoided the accident once the bicyclist first could have observed the motor vehicle. In 40% of the cases, it was judged that the bicyclist could have observed the approaching motor vehicle early enough to have avoided the accident but failed to search in the direction of the motor vehicle until an accident was imminent. In about one-third of the cases, the motor vehicle was stopped at the intersection and was observed by the bicyclist long before the accident: the bicyclist proceeded with the assumption that the stopped vehicle would remain stationary until he had passed.

Unlike Problem Type 6, it was found that only 20% of the bicyclists underestimated the length of the amber phase. Most bicyclists were perfectly aware that the amber phase was about to terminate but assumed that all motor-vehicle traffic would remain stationary or yield to them.

The bicyclist age distribution for Problem Type 7 was similar to that for Problem Type 6. The median age of the bicyclists was 15.2 years; about 25% were 16 years of age or older. Only five percent of the bicyclists were younger than 12 years of age or older than 33 years of age.

Special Note on Problem Types 6 and 7

The data from the post-crash interviews are not sufficiently precise to make an accurate determination of whether an excessively short amber phase contributed to Type 6 and Type 7 accidents. Although most bicyclists freely admitted that they entered the intersection after the onset of the amber phase, many reported that they were very close to the junction when the light changed from green to amber. Judging from the bicyclists' reports, it appears that the amber phase at some of the accident sites was *not* long enough to accommodate the passage of a bicycle plus a reasonable error or "fudge" factor.

Based upon analytical considerations alone, the authors believe that the amber phase on most roadways with four or more lanes is too short to permit a slow-moving bicycle to cross the entire roadway during the amber phase. For instance, a bicyclist traveling at 10 MPH requires 4.1 seconds to cross a street 60 feet wide. The amber phase on such a street is usually three seconds and would rarely be greater than 3.5 seconds. So, even at 10 MPH, the bicyclist has insufficient time to cross a relatively narrow four-lane roadway. Obviously, many young bicyclists travel at speeds slower than 10 MPH. For these reasons, it appears that a thorough study should be made of the adequacy of the amber phase for bicycle traffic.

Other Class B (1.2% Fatal; 1.7% Non-Fatal)

The sample contained a small number of cases in which the bicyclist entered a signalized intersection well after the onset of the red-signal phase. Because of the small number of such cases and because of the lack of commonality in the accident-generation process, it was not possible to define one or more clear-cut problem types for these cases. Therefore, the cases were classified into "Other Class B."

If the data base for bicycle/motor-vehicle accidents is expanded in the future, it is probable that at least three additional Class B problem types would be revealed. One type would include cases in which a bicycle failure or a skill deficiency prevented the bicyclist from stopping for the red signal. A second type would include cases in which the bicyclist was suffering from a physical or mental impairment (particularly alcohol) and therefore failed to monitor the signal carefully. A third type would include cases in which the bicyclist knowingly failed to stop at the intersection because he assumed he could successfully dodge or otherwise evade approaching motor vehicles. Examples of each of these types of accidents were found among the cases classified into "Other Class B." However, the findings of the present study indicate that such problem types would occur infrequently. The present data, and other samples of accident reports that have been examined by the authors, indicate that few bicycle/motor-vehicle accidents occur when bicyclists enter an intersection when the signal is clearly red. Although most readers know that failing to stop for a red signal is not at all uncommon for bicyclists, the bicyclists who engage in this hazardous activity apparently exercise a good deal of caution when doing so.

COUNTERMEASURE APPROACHES FOR CLASS B PROBLEM TYPES

The evidence is clear that Type 5 accidents seldom occur when the bicyclist stops or slows his speed significantly before entering an intersection controlled by a stop or yield sign. Although it is necessary for bicyclists to search for and evaluate the closing velocity of approaching motor vehicles, bicyclists usually perform the search and evaluation functions in an adequate manner when they consider it necessary to slow or stop at an intersection. Thus, a primary goal of countermeasures for Problem Type 5 is to induce bicyclists to slow their speed considerably or, preferably, come to a complete stop before entering a signed intersection. The other objective of countermeasures for Problem Type 5 is to teach bicyclists to avoid multiple-threat accidents at signed intersections.

The objective of countermeasures for Problem Types 6 and 7 is to prevent bicyclists from entering a signalized intersection when it is not possible for them to clear the intersection before the termination of the amber phase. An additional objective for Problem Type 7 is to teach bicyclists and motorists to avoid multiple-threat accidents at signalized intersections.

The objective of countermeasures for Other Class B accidents is to prevent bicyclists from entering a signalized intersection against a red signal.

Environmental Changes

Roadway designs to modify the bicyclist's pre-crash course. Considerable thought has been given to engineering designs that would cause bicyclists to reduce their speed or stop at signed intersections, but the authors have been unable to identify any engineering techniques that would be effective, financially feasible, and acceptable to the bicycling and motoring public. The speed-control bumps or baffles mentioned earlier might cause bicyclists to reduce their speed, but it would be necessary to install these devices at a very large number of intersections if they are to have a significant impact on Problem Type 5. Furthermore, it would be necessary to place them across the entire roadway since it cannot be assumed that bicyclists will always be riding close to the right-hand curb or even on the proper side of the roadway. Such devices almost certainly would be found highly objectionable by motorists, particularly if it was necessary for motorists to drive over such devices after they had already passed through the intersection--as would be required if the devices were placed across the full width of the roadway. Although an engineering solution to this problem is not apparent at this time, it is believed that the engineering community should be informed of the problem and tasked with the responsibility for identifying and evaluating potential engineering solutions.

Modification of signal phase. An obvious engineering solution for Problem Types 6 and 7 is to lengthen the amber phase of the traffic signal, but few traffic engineers consider this to be a practical solution. The traffic engineers who have expressed their view on this matter are unanimous in their belief that increasing the length of the amber phase enough to accommodate slow-moving bicycles would create more problems than would be solved. They claim that increasing the amber phase by a significant amount would seriously degrade the efficiency of the traffic system. More importantly, the engineers claim that increasing the amber phase beyond about 4.5 to 5.0 seconds would result in a large number of encroachments by motorists--with a resulting increase in motor-vehicle accidents at signalized intersections. (A slow-moving bicyclist riding at four MPH requires about ten seconds to ride across a street 60 feet wide.)

A more feasible engineering solution for Type 6 or 7 accidents is to provide a special caution signal that would inform bicyclists when they have insufficient time to clear the intersection before the termination of the amber phase. Additional research would be required to identify the most cost-effective way to provide such a signal. The authors believe that researchers should first consider the feasibility of employing the existing pedestrian signal devices to provide caution signals for bicyclists. It is probable that most bicyclists would be opposed to regulations requiring them to stop at the onset of the DON'T WALK signal developed for pedestrians. However, it may be possible to modify the existing timing devices and signs to provide a special phase and a special message for bicyclists. For instance, it may be possible to modify the existing devices such that the message on the pedestrian sign would change from DON'T WALK to DON'T WALK/RIDE at the onset of the caution phase for bicyclists.

Bicycle Modifications

It was judged that many of the motorists involved in Class B accidents could have avoided a collision if their attention had been attracted to the bicyclist and/or if the bicyclist had not been obscured by standing motor vehicles (multiple-threat accidents). Consequently, devices that would increase the conspicuity and vertical dimension of the bicycle may serve to reduce the incidence of Class B accidents--particularly those that occur in the second half of the roadway. That is, motorists approaching from the bicyclist's right in the far lane(s) have more time to respond because the bicyclist must travel across one or more traffic lanes before intersecting the motorist's path.

The potential reduction in Class B accidents may not be sufficient justification for the development and widespread use of devices to increase the conspicuity and vertical dimension of bicycles. However, the potential reduction in Class B accidents must be considered when evaluating the total benefits to be derived from such devices.

Evaluation and Training

Bicyclists. A careful study of the accident-generation process for Problem Types 5, 6, and 7 shows that these accidents were seldom due to the bicyclist's willingness to accept an uncommonly high degree of risk, and were never due to the bicyclist's misunderstanding of the laws governing behavior at controlled intersections. Rather, the bicyclist's critical actions were primarily due to: misjudgment of the risk associated with the critical action, misjudgment of the length of the amber phase, failure to recognize a "multiple-threat" situation, competing needs, and momentary distractions. Therefore, an educational program for bicyclists must be developed to accomplish the following objectives:

- Modify bicyclists' assessment of the risk associated with entering a signed intersection without slowing or stopping.
- Modify bicyclists' assessment of the risk associated with entering a signalized intersection during the amber phase.
- Teach bicyclists to search for and recognize all types of visual obstructions and the exact behavioral sequence to follow when obstructing objects are present.
- Teach bicyclists to recognize and cope with a "multiple-threat" situation at both signed and signalized intersections.
- Teach bicyclists the proper behavioral sequence when entering a controlled intersection when visual obstructions are *not* present.
- Teach bicyclists the importance of momentary distractions and how to cope with them.

If the education is to be received before a significant number of accidents already have occurred, education to curtail Type 5 accidents must be introduced during the second or third grade (7- or 8-year-old bicyclists). Education to curtail Types 6 and 7 accidents may be delayed until the fifth or sixth grade (10- or 11-year-old bicyclists) without sustaining significant losses.

Motorists. An education program that would serve to increase motorists' awareness of multiple-threat situations may prove beneficial in reducing multiple-threat accidents, particularly at signed intersections. Certainly, motorists in standing vehicles should be taught to always check for other approaching motor vehicles before motioning bicyclists to cross in front of them. It may be possible to develop a standardized hand signal or horn signal that motorists can use to inform bicyclists that it is *not* safe to pass. Also, some benefit may result from educating motorists that slow-moving bicyclists may not have enough time to clear the intersection during the amber phase.

Regulations and Enforcement

Existing regulations governing behavior at signed intersections appear to be adequate. However, the enforcement of these regulations appears to be inadequate in most areas. Inadequate enforcement is partly due to the fact that police officers spend a relatively small amount of time patrolling the residential areas in which Type 5 accidents usually occur. Inadequate enforcement is also due to the officer's reluctance to spend his time issuing citations to bicyclists. Even when citations are issued, the typical penalty is so insignificant that citations are not an effective deterrent for most bicyclists. Therefore, what is needed is an enforcement program which ensures that the target areas will be properly patrolled, the bicyclists who are observed riding through signed intersections will be issued a citation, and the citation carries with it a penalty great enough to deter bicyclists from engaging in this dangerous activity.

The regulations governing bicyclists' behavior at signalized intersections may be inadequate. The present regulations do not prohibit bicyclists from entering a signalized intersection during the amber phase. Until better countermeasures for Problem Types 6 and 7 are developed, it may be beneficial to require bicyclists to adhere to the regulations that apply to pedestrians; e.g., "No pedestrian shall enter the roadway or cross any part of a roadway, or proceed from or to a safety zone against a yellow or caution signal."

CLASS C PROBLEM TYPES

Problem Class C consists of five problem types that together accounted for 2.4% of the fatal cases and 18.7% of the non-fatal cases. The Class C problem types are listed in Table 35 along with the proportions of fatal and non-fatal cases classified into each problem type. All Class C

TABLE 35

PROBLEM CLASS C--MOTORIST TURN-MERGE/DRIVE THROUGH/DRIVEOUT

		FATAL (N=166)	NON-FATAL (N=753)
TYPE 8	MOTORIST TURN-MERGE: COMMERCIAL DRIVEWAY/ ALLEY	---	5.3%
TYPE 9	MOTORIST TURN-MERGE/DRIVE THROUGH: INTERSECTION CONTROLLED BY SIGN	1.2%	10.2%
TYPE 10	MOTORIST TURN-MERGE: INTERSECTION CONTROLLED BY SIGNAL	---	1.9%
TYPE 11	MOTORIST BACKING FROM RESIDENTIAL DRIVEWAY	---	.8%
TYPE 12	MOTORIST DRIVEOUT: CONTROLLED INTERSECTION	1.2%	.5%
TOTAL CLASS (N: FATAL = 4; NON-FATAL = 141)		2.4%	18.7%

accidents occurred as the motorist entered an uncontrolled roadway from a driveway, alley, or from a controlled leg of an intersection. Except for Problem Type 12, all the motorists stopped or slowed significantly at the junction before proceeding into the intersecting roadway. In nearly every case, the motorist entered the intersection without having observed the bicyclist that was approaching the junction. The motorist's failure to observe the bicyclist was often the result of the bicyclist's unexpected location--on the sidewalk or on the wrong side of the roadway. Many of the bicyclists involved in Class C accidents observed the motor vehicle soon enough to have avoided the accident, but failed to initiate evasive action because of the erroneous assumption that they had been or would be observed by the motorist.

The vast majority of collisions occurred shortly after the motorist accelerated from a stopped position. This fact accounts for the low incidence of fatalities for Class C accidents. When the motor vehicle struck the bicycle, the impact velocity was low and the bicyclist usually careened off the front of the motor vehicle. When the bicyclist struck the motor vehicle, the impact velocity was solely a function of the bicyclist's speed. Apparently, the bicycle speed was not often great enough to produce fatal injuries. Because of the low incidence of fatal accidents, Class C accidents must be considered less important than other types of accidents that account for fewer accidents but more fatal injuries.

PROBLEM-TYPE DESCRIPTIONS

Problem Type 8 (5.3% Non-Fatal; No Fatal)

All of the cases classified into Problem Type 8 occurred as the motorist was entering a roadway from a driveway that served one or more commercial establishments. In a slight majority of cases, the motorist was entering a street with four or more lanes (55%); most of the remaining cases occurred as the motorist was entering a two-lane street (40%). Only five percent of the cases occurred on a rural roadway. Ninety-three percent of the accidents occurred during the daytime and 88% occurred between 11:00 AM and 7:00 PM.

It was found that 82% of the motorists came to a complete stop at the roadway junction. Eighteen percent of the motorists slowed to a low speed when approaching the junction but failed to bring their vehicle to a complete halt before proceeding into the roadway. In every case of this type, the motorist failed to observe the approaching bicyclist even though it was judged that the search function was performed in a manner that would be considered normal for motorists in this situation. As explained below, the reason for the motorist's failure to observe the bicyclist was found to differ somewhat for each of the subtypes illustrated in Figure 33.

- Bicyclist on sidewalk approaching from the right (32.5%)--It was found that the motorist's view of the bicyclist was obstructed in over half of these cases. In the remaining cases, the motorist failed to search far enough along the driveway to observe the approaching bicyclist. Apparently, the motorists searched in a manner that they considered adequate to detect approaching pedestrians. That is, they judged that a pedestrian located more than a few feet from the driveway junction could not possibly arrive at the junction before they had passed, so considered it unnecessary to scan the sidewalk more than a few feet from the junction. Because of the search pattern of motorists in this situation, it is probable that the removal of visual obstructions would have little effect on the incidence of accidents of this type.

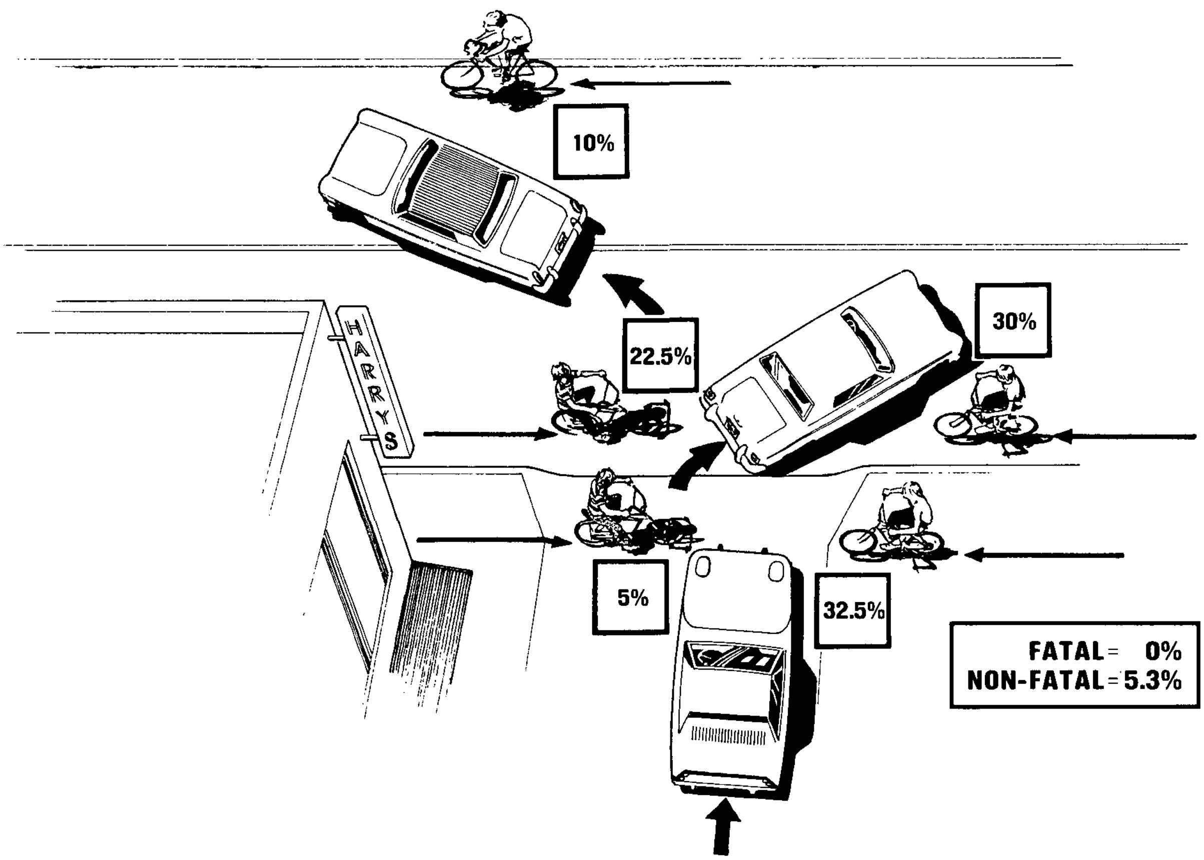

Figure 33. Illustration of Problem Type 8, *Motorist Turn-Merge: Commercial Driveway/Alley.*

(NOTE: The building was drawn in the above illustration to indicate that this type of accident occurs at the junction of a *commercial* rather than a residential driveway/alley. Although a building sometimes obstructed the operator's view in accidents of this type, buildings were not the most frequent type of obstructing object.)

- Bicyclist on roadway approaching from the right (30%)--It was found that the motorist's view of the approaching bicyclist was obstructed in about 25% of the cases. In the remaining cases, the motorist failed to search in the bicyclist's direction because he did not expect a hazard to be approaching from that direction. This pattern was found to be particularly prevalent when the motorist was intending to make a right-hand turn. Again, it is unlikely that the removal of visual obstructions would effect a reduction in accidents such as these.

- Bicyclist on sidewalk approaching from the left (5%)--This variation of Problem Type 8 occurred so infrequently that it is not possible to draw valid inferences about the reasons for the motorist's failure to observe the approaching bicyclist. However, it is probable that the reasons are the same as for the cases in the next paragraph.

- Bicyclist on street approaching from the left (22.5%)--In slightly over half of these cases, the motorist searched in the bicyclist's direction, but failed to observe the bicyclist even though he was clearly visible and the lighting conditions were good. Apparently, the bicyclist's image appeared in the motorist's field of view (on motorist's retina) one or more times but was not consciously perceived. This phenomenon is sometimes referred to as "selective perception." In about one-fifth of the cases, the motorist's failure to detect the bicyclist was because of darkness, inadequate bicycle lighting, or both. In the remaining cases, the motorist failed to search in the bicyclist's direction. Surprisingly, not a single case was found in which the motorist's view of the bicyclist was obstructed.

- Bicyclist in far lane approaching from the right (10%)--This variation of Problem Type 8 occurred infrequently. However, in every case of this type, it was found that the motorist searched in the bicyclist's direction but failed to observe him. Only one-fourth of the cases of this type occurred at night and involved inadequate bicycle lighting. Judging from the characteristics of the traffic context in which accidents of this type occurred, it seems reasonable to assume that information overload and/or attentional conflict would be contributing factors in a substantial number of cases. Information overload is particularly likely in cases in which the motorist was attempting to turn left across a busy multiple-lane roadway.

The finding that fewer sidewalk accidents occurred when the bicyclist was approaching from the motorist's left is a significant finding. There is no reason to expect that bicyclists ride on the sidewalk in one direction more frequently than another, so it seems reasonable to conclude that accident likelihood is less when the bicyclist is traveling in the same direction as traffic in the adjacent traffic lane. The apparent reason for this finding is that motorists must search almost 90 degrees to their left in order to check for traffic that may be approaching in the near traffic lane. Since the bicyclist is often only a few feet from the traffic lane, he is likely to be detected, even though the motorist is mainly concerned with checking for approaching motor vehicles.

The bicyclist's preview time was critically limited by a visual obstruction in about 15% of the cases. In all but one of these cases, the bicyclist was riding on the sidewalk. In 25% of the cases, the bicyclist failed to search in the direction of the motorist until an accident was imminent. In 60% of the cases, the bicyclist observed the motor vehicle early enough to have easily avoided the accident but proceeded with the assumption that the motor vehicle would not enter the roadway until he had passed. Many of the bicyclists reported that they temporarily slowed their speed until they observed the motorist scanning in their direction. The eye contact with the motorist led the bicyclist to assume that he had been detected by the motorist when, in fact, he had not.

The data revealed that the bicyclist's decision to ride facing traffic was based upon convenience rather than ignorance of the law. Every bicyclist was questioned about this matter, and every bicyclist reported that he knew--before the accident occurred--that it is unlawful to ride facing traffic.

Problem Type 8 involves bicyclists whose age varies widely. The median age of the bicyclists was 15.4 years. Only five percent were seven years of age or younger, and five percent were 49 years of age or older. About 50% of the bicyclists were between 13 and 17 years of age.

Problem Type 9 (1.2% Fatal; 10.2% Non-Fatal)

Problem Type 9 was one of the two most frequently occurring problem types, but only 1.2% of the fatal accidents were classified into this problem type. The reason for this large difference, as was explained earlier, is the generally low motor-vehicle speeds and resultant impact velocities for accidents that occur in this manner. The nature of the accident-generation process for Problem Type 9 is highly similar to that defined above for Problem Type 8. The main difference is that all the cases in Problem Type 9 occurred at a signed intersection rather than at the junction of a roadway and a commercial driveway. For Problem Type 9, the bicyclist approached the junction on an uncontrolled leg of the intersection, and the motorist approached the junction on an orthogonal leg that was controlled by a stop sign (97%) or a yield sign (3%). Accidents of this type occurred in both urban and rural areas and occurred on a variety of roadway types. The characteristics of the uncontrolled roadway are as follows: (a) a two-lane urban street (46%), (b) an urban street with more than two lanes (43%), (c) a two-lane rural roadway (8%), and (d) a rural roadway with more than two lanes (3%). This type of accident typically occurred during the daytime, but a significant number (17%) occurred during darkness. Ten percent of the accidents occurred between 7:00 AM and 9:00 AM, and another 66% occurred between 12:00 PM and 8:00 PM.

Ninety-four percent of the motorists came to a complete stop before entering the intersection, and 95% of the motorists entered the intersection without having observed the approaching bicyclist. When the motorist observed the bicyclist before entering the intersection, the accident occurred because the motorist misjudged the bicyclist's intended path. Usually, the motorist incorrectly assumed that the bicyclist was going to turn before intersecting the intended path of the motorist. The reasons for the motorist's failure to observe the bicyclist before entering the intersection are described below, within the context of the four subtypes illustrated in Figure 34.

- Bicyclist in near lane(s), approaching from the right (54%)--Although not illustrated in Figure 34, about one-fifth of these cases involved a bicyclist who was riding on the sidewalk before entering the roadway. In the remaining cases, the bicyclist was in the roadway, riding facing traffic. However, the reason the motorist failed to observe the bicyclist was the same for all of these cases; namely, the motorist failed to scan in the direction of the bicyclist because he did not expect a hazard to be approaching from that direction. In this context, the typical motorist searches to his right for traffic approaching in the far lanes and to his left for traffic approaching in the near lane; motorists seldom search 90 degrees to their right because they have seldom, if ever, encountered a threat approaching from that direction.
- Bicyclist in near lane(s), approaching from the left (22%)--When the motorist failed to observe the bicyclist approaching from the left in the near lane, it was most often due to inadequate search or selective perception. However, about one-third of these cases occurred during darkness and involved a bicyclist with inadequate bicycle lighting.

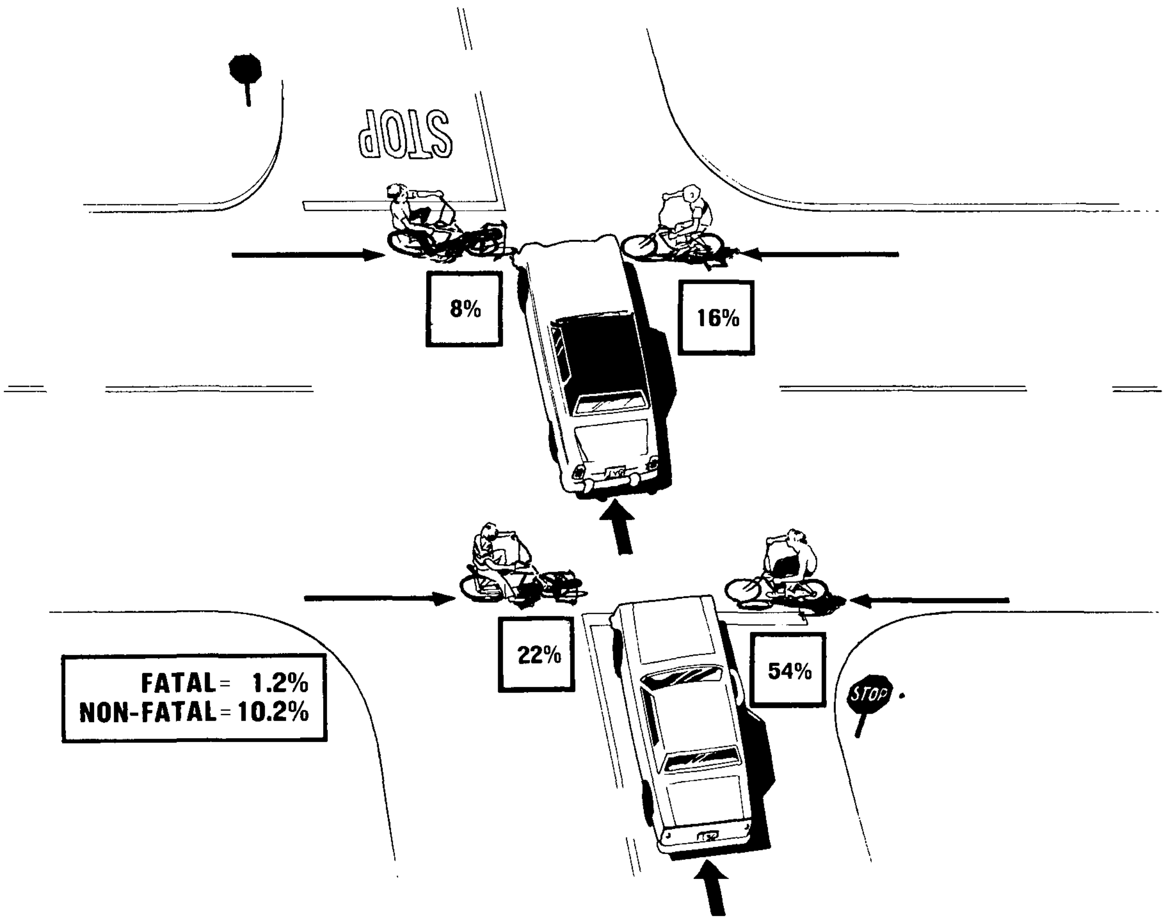

Figure 34. Illustration of Problem Type 9, *Motorist Turn-Merge/Drive Through: Intersection Controlled by Sign.*

- Bicyclist in far lane(s), approaching from the right (16%)--In these cases, the motorist's failure to observe the bicyclist was usually due to inadequate search; but about one-fourth of the cases occurred during darkness and involved a bicyclist with inadequate lighting.
- Bicyclist in far lane(s), approaching from the left (8%)--More than half of the accidents of this type occurred during darkness and involved a bicyclist with inadequate lighting. In the remaining cases, the motorist failed to search in the bicyclist's direction because he did not expect a hazard to be approaching from that direction.

In 13% of the cases, the bicyclist failed to search in the motorist's direction until it was too late to avoid the accident. The bicyclist proceeded through the intersection without searching, because he knew he had the right of way and assumed vehicles on intersecting roadways would yield to him. However, in 83% of the cases, the bicyclist observed the motor vehicle soon enough to have easily avoided the accident. The bicyclist's failure to initiate evasive action was due to his faulty assumption that he had been or would be detected by the motorist, and that the motorist would remain stationary until he had passed through the intersection. Surprisingly, nearly all the bicyclists who were riding facing traffic observed the motor vehicle long before the collision. All of these bicyclists were aware that riding facing traffic was unlawful, but still assumed that they would be observed by the motorist. The faulty assumption that they would be detected by the motorist was also prevalent among bicyclists who were riding during darkness.

Problem Type 9 involved an older group of bicyclists than any problem type discussed previously. The median age of the bicyclists involved in this type of accident was 16.3 years, and few of the bicyclists were very young. For instance, it was found that less than five percent of the bicyclists were younger than ten years of age. Slightly over 50% of the bicyclists were between 13 and 20 years of age.

Problem Type 10 (1.9% Non-Fatal; No Fatal)

Problem Type 10 occurred infrequently and is simple and straightforward to explain. In all cases of this type, the motorist came to a complete stop at a signalized intersection, searched for traffic approaching from the left in the near traffic lanes, and proceeded to make a right-turn-on-red. In every case, the motorist failed to observe the bicyclist before entering the intersection. Figure 35 illustrates that 85% of the Type 10 accidents involved a bicyclist who was riding facing traffic. The motorist failed to observe the bicyclist because he did not search in the bicyclist's direction. In 86% of the cases, the bicyclist observed the motor vehicle, but proceeded through the intersection with the faulty assumption that he had been or would be detected by the motorist.

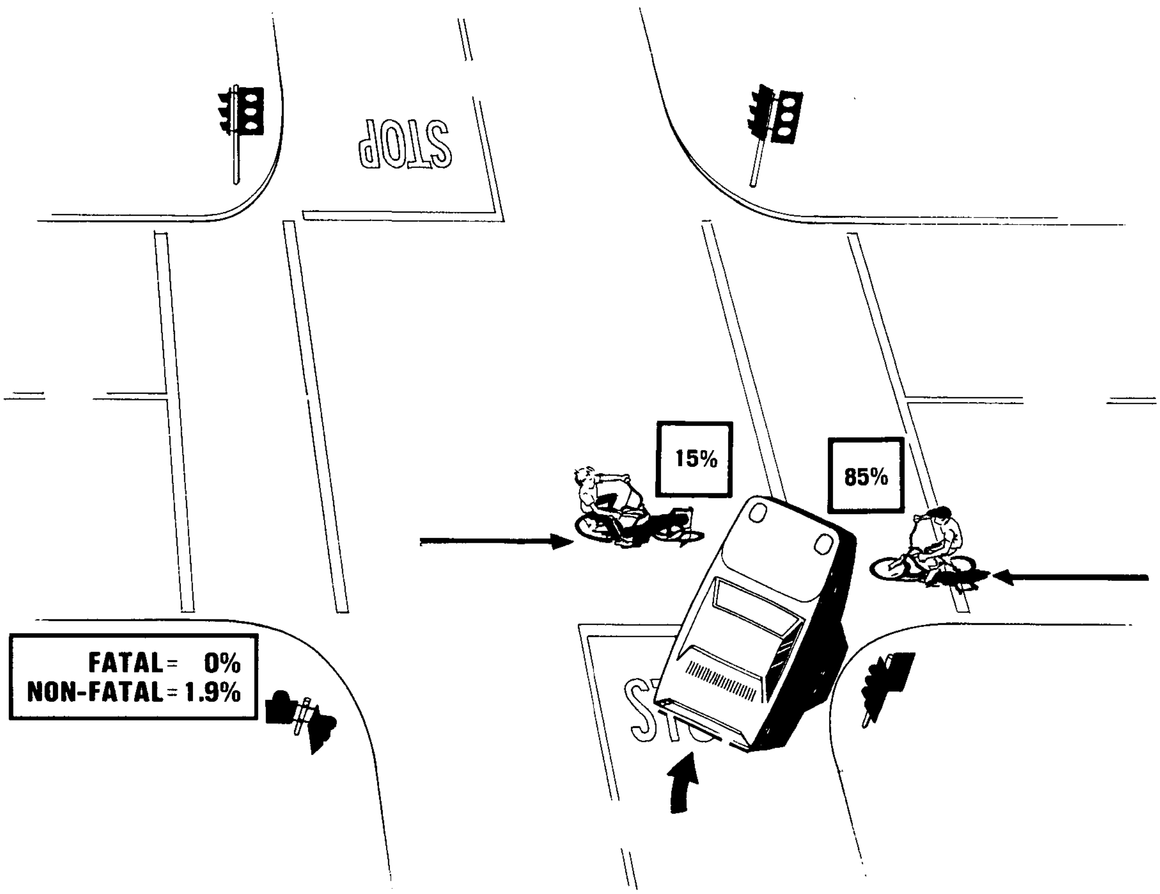

Figure 35. Illustration of Problem Type 10, *Motorist Turn-Merge: Intersection Controlled by Signal.*

Although the sample size was too small to provide an accurate indication of the age distribution of bicyclists involved in Type 10 accidents, it was found that the small number of bicyclists who were involved in this type of accident varied in age from ten years to over 70 years of age. Very young bicyclists are probably involved in this type of accident only infrequently, because they seldom ride in the types of locations in which such accidents occur.

Problem Type 11 (.8% Non-Fatal; No Fatal)

Accidents classified into Problem Type 11 occurred when a motorist backed from a residential driveway into the path of an approaching bicyclist (see Figure 36). All of the bicyclists were riding in the street

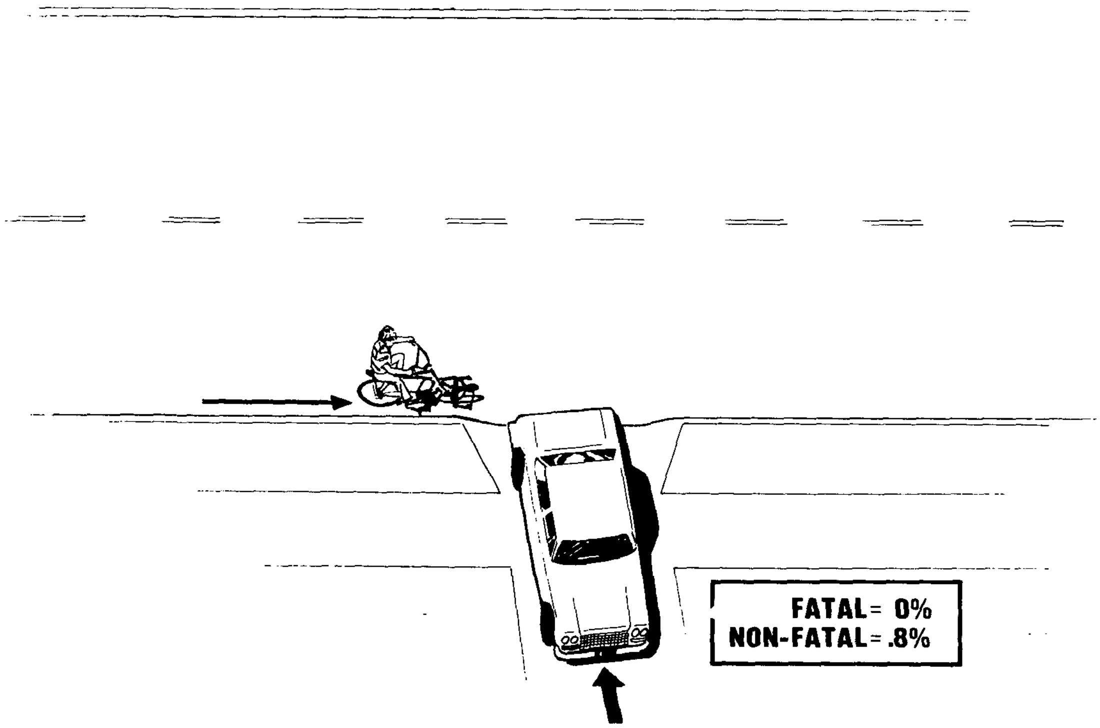

Figure 36. Illustration of Problem Type 11, *Motorist Backing from Residential Driveway.*

and only one bicyclist was riding facing traffic prior to the collision. The motorist's view of the bicyclist was degraded in every case. One-third of the accidents occurred during darkness; the motorist's view of the bicyclist was obstructed by vegetation or parked motor vehicles in all of the remaining cases.

One of the main reasons for including this problem type was to show the infrequency with which it occurs. Since bicyclists must encounter motor vehicles backing from residential driveways very often and since the motorist's view in this situation is often obstructed by external objects or parts of the motor vehicle's structure, one would expect that Type 11 accidents would occur quite frequently. However, the research findings showed that this type of accident occurs far less often than accidents in which motorists are exiting a driveway in a forward direction (Problem Type 8). Although the reason for this large difference is not known for certain, it seems reasonable to assume that bicyclists perceive backing vehicles as potential threats and seldom make the erroneous assumption that they have been detected by the driver of a backing vehicle. It is also possible that motorists recognize the hazardousness of this situation and exercise more caution when backing from a driveway than when exiting a driveway in a forward direction.

The age range of the bicyclists who were involved in Type 11 accidents varied from five to 25 years of age.

Problem Type 12 (1.2% Fatal; .5% Non-Fatal)

As is illustrated in Figure 37, Problem Type 12 occurred when the motorist passed through a stop sign without making any attempt to stop or slow. This type of accident occurred infrequently, but is likely to result

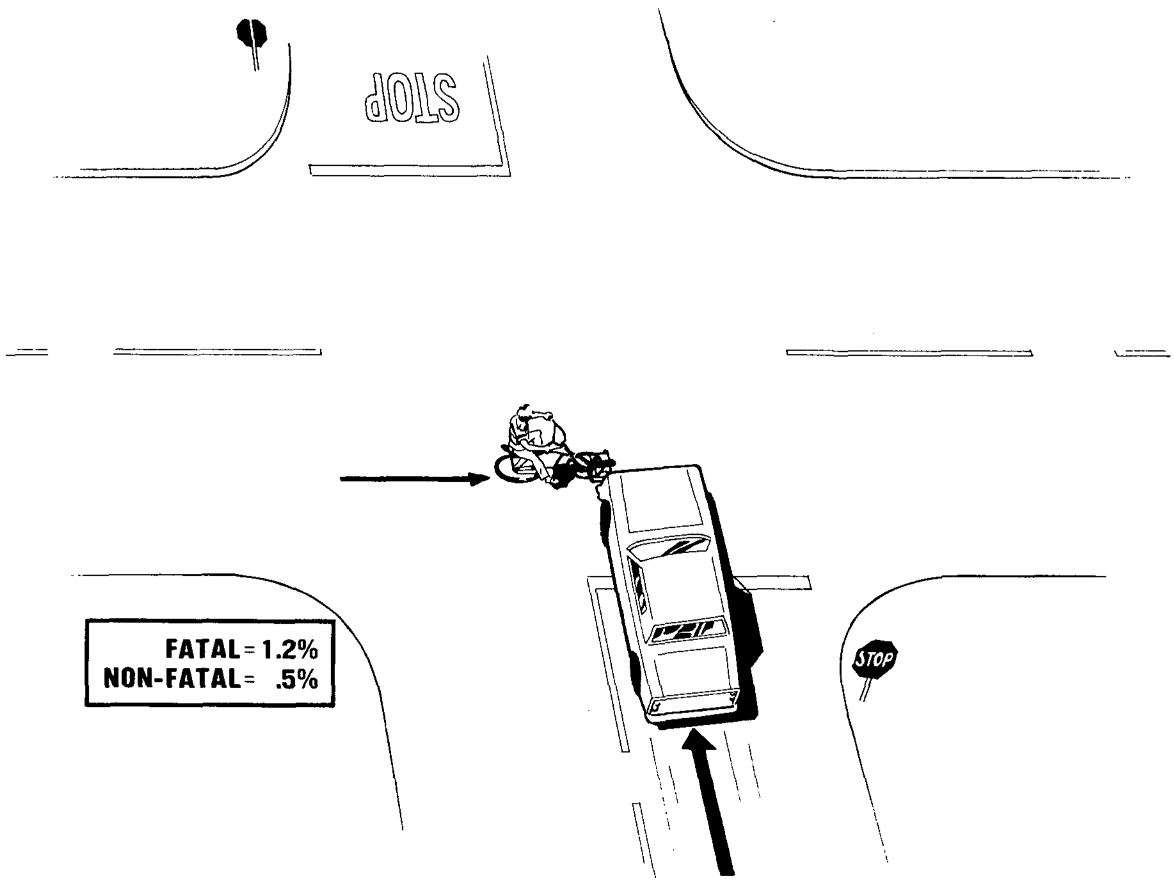

Figure 37. Illustration of Problem Type 12, *Motorist Driveout: Controlled Intersection.*

in fatal injuries to the bicyclist when it does occur. No inferences can be made about the nature of the accident-generation process for this type of accident because of the small sample size. However, it is interesting to note that three out of four motorists in the non-fatal sample failed to observe the stop sign; the remaining motorist in the non-fatal sample was unable to stop because of faulty brakes. All of the fatal cases involved an intoxicated motorist.

COUNTERMEASURE APPROACHES FOR CLASS C PROBLEM TYPES

Special Note on Wrong-Way Riding

It was found that 52% of all Class C accidents involved a bicyclist who was riding on the wrong side of the roadway (riding facing traffic); this number does not include accidents in which the bicyclist was riding on the sidewalk. Since Class C accidents also occur when the bicyclist is riding on the *correct* side of the roadway, it is legitimate to ask whether the accidents that involved a wrong-way riding bicyclist would have occurred if the bicyclist had been riding *with* traffic rather than *against* traffic. In short, the question is this: If countermeasures could be developed to induce all bicyclists to ride on the correct side of the roadway, what proportion of the Class C accidents would still occur?

A purely objective answer to this question would require accurate data on the relative amount of time the general population of bicyclists spend riding with and against traffic. Unfortunately, such data are not presently available. So, an assessment of the potential value of countermeasures to curtail wrong-way riding must be based upon opinion. Based upon casual observation at a number of locations throughout the United States, the authors and their colleagues who bicycle frequently believe that most bicyclists ride on the correct side of the roadway most of the time.

Some indirect support for this view was obtained from the data compiled during this study. Although the bicyclists who were interviewed were not questioned systematically about the frequency with which they ride on the wrong side of the roadway, all bicyclists *were* asked if they knew that riding facing traffic was unlawful; and, if so, why they chose to ride facing traffic on the day of the accident. With only one exception, the bicyclists reported that they knew riding facing traffic was unlawful. Convenience in reaching their destination was the most common reason for riding facing traffic on the day of the accident. An examination of the bicyclists' pre-crash course revealed the following typical pattern.

> The bicyclist commenced his trip and rode most of the way on the correct side of the roadway. As the bicyclist neared his destination, he initiated a left-hand turn at the last intersection he encountered before reaching his destination. The bicyclist's destination was on the left-hand side of the roadway and he turned at the intersection to avoid having to make a left-hand turn mid-block where no controls were present and where the roadway was sometimes divided by a raised median or another type of barrier. After having crossed the roadway, the bicyclist turned right and continued in the same direction that he was traveling prior to his turns. Some bicyclists rode on the sidewalk and others rode in the roadway--facing traffic. Typically, the bicyclist's destination was less than a block from the point at which he commenced riding facing traffic, and the accident occurred during the time the bicyclist was traveling this short distance.

Based upon the composite information now available, the authors estimate that the amount of time bicyclists spend riding on the correct side of the roadway may be 50 or 100 times greater than the amount of time they spend riding facing traffic. If this estimate is valid, countermeasures that would curtail wrong-way riding would eliminate about one-half of all Class C accidents. Readers who have a different view on the relative exposure of wrong-way riding bicyclists can estimate the percent reduction in Class C accidents with the following simple equation:

$$P = (1-p)\ (52\%)$$

where P = Percent reduction in Class C accidents

p = Total time spent riding facing traffic divided by total time spent riding with traffic

Discussions with bicyclists and their parents have led the authors to conclude that few persons understand why riding facing traffic is prohibited by law. Many persons have assumed that the reason for this law is to avoid head-on accidents between bicycles and motor vehicles. This erroneous assumption has led some persons to argue that the injuries resulting from a head-on accident would not be significantly greater than those resulting from an overtaking accident and that riding facing traffic provides the bicyclist with a better opportunity to detect and evade motor vehicles that are traveling close to the edge of the roadway. This rationale has caused many parents to advise their children to ride facing traffic, even with the full knowledge that it is unlawful. Thus, there is a clear need to educate both bicyclists and the parents of bicyclists about how and why accidents occur when a bicyclist chooses to ride facing traffic. At the same time, the bicyclists and their parents should be informed of how and why overtaking accidents occur and what can be done to avoid them. Such training is recommended below, along with other countermeasure approaches for Class C accidents.

Environmental Changes

Many of the motorists involved in Type 8 accidents were attempting to turn left from a driveway onto a busy multi-lane roadway. The motorist's information processing capacity was heavily loaded by the requirement to search the near lanes to the left, the far lanes to the right, and the sidewalk in both directions. The motorist's information processing load and attentional conflict in this situation could be reduced by providing a sheltered median in the center of the roadway. A sheltered median would enable a motorist to concentrate on only half of the traffic lanes at any one time. That is, the motorist would first search for traffic approaching from the left; when an acceptable gap in traffic is observed, he would proceed to the sheltered median and stop. Once he reached the sheltered median, his entire attention could be devoted to searching for traffic approaching from the right.

The development of sheltered medians probably would not be cost-effective if the entire benefit was a reduction in Type 8 bicycle accidents. However, sheltered medians would almost certainly result in a reduction in accidents involving pedestrians and other motor vehicles. Therefore, an assessment of the cost-effectiveness of this countermeasure must be based on its potential for reducing all types of traffic accidents.

Bicycle Modifications

Many Class C accidents occurred because the motorist failed to observe a bicyclist who was riding in an expected location and who was clearly visible. In many instances, both the bicyclist and the motorist reported that the bicyclist went undetected even though the motorist searched in the bicyclist's direction. Even when the motorist failed to look directly at the bicyclist, the motorist's scan pattern was such that the bicyclist usually appeared in the motorist's peripheral field of view.

In addition, there were a substantial number of cases that occurred during darkness and involved an inadequately lighted bicycle. In at least one-half of the cases that occurred during darkness, the bicycle was equipped with lights that met existing requirements; still, the bicyclist went undetected by the motorist. When the motorist searched in the bicyclist's direction but failed to detect him, the lighting equipment on the bicycle must be judged inadequate, whether or not the lighting equipment met existing specifications.

There is little question that many Class C accidents would be eliminated if a method could be devised to increase the conspicuity of bicycles during both daylight and darkness. Increasing the nighttime conspicuity of bicycles is important, but not nearly so important as increasing the conspicuity of bicycles during the daytime. Since there are no clearly proven techniques for increasing bicycle conspicuity to an acceptable level, it can only be recommended that research be initiated to develop and evaluate techniques for accomplishing this important goal. In addition, the findings of this study suggest the need to reexamine the adequacy of existing standards for front-lighting equipment.

Education and Training

Bicyclists. Nearly all bicyclists are aware that riding facing traffic is unlawful, so there is no need to educate bicyclists about the law. Some persons have suggested that bicyclists should be taught the techniques that are required to ride facing traffic in a safe manner. However, it is unlikely that it would be possible to teach bicyclists techniques that would be as safe as riding on the correct side of the roadway. Furthermore, it is probable that such training would serve to promote wrong-way riding and thereby increase the number of wrong-way riding accidents, even though the training reduced accident *rate* for this type of accident. For these reasons, it seems that the most effective alternative is to design a training program to curtail wrong-way riding. To be effective, the program must convince the bicyclists (and their parents) that riding facing traffic is a hazardous thing to do and that accident likelihood is increased greatly when a bicyclist chooses to ride on the wrong side of the roadway. At the same time, the bicyclists and their parents must be informed that riding on the correct side of the roadway will not lead to increased numbers of accidents if the bicyclist exercises reasonable caution in selecting where and when he will ride.

For every problem type in Class C, it was found that a large proportion of the bicyclists observed the motor vehicle early enough to have easily avoided the accident. This finding was the same regardless of the bicyclist's location and direction of travel. The relatively small number of cases in which the bicyclist failed to search in the motorist's direction were due mainly to the bicyclist's fundamental assumption that all intersecting traffic would yield to him. One means of preventing such accidents is to modify bicyclists' views about the infallibility of motorists. A safety-education program developed for bicyclists should teach them the typical search patterns of motorists in this type of traffic context, the limitations of the human visual system, and the types of accidents that occur because a motorist fails to observe a bicyclist that may be clearly visible. This information must be presented in a manner that will serve to modify bicyclists' assumptions that they have been or will be detected by motorists who are preparing to enter an uncontrolled roadway from a driveway or from a controlled leg of an intersection.

Many existing educational materials instruct both bicyclists and pedestrians to establish eye contact with a motorist before proceeding across a stopped motor-vehicle's path. This education is probably counter-productive; it suggests that the bicyclist or pedestrian can safely assume that he has been detected by the motorist if he has established eye contact. This is a clearly invalid assumption that led to a substantial proportion of Class C accidents.

Many bicycling experts advocate riding in the center of the traffic lane rather than along the right-hand edge of the roadway. They claim that riding in the center of the traffic lane increases the chances of being observed by motorists who are preparing to enter the roadway from intersecting streets or driveways. Also, they argue that riding in the center of the lane provides a greater buffer zone between the bicycle's path and the position at which motor vehicles stop before entering the roadway. Thus, riding in the center of the traffic lane provides additional time for the bicyclist to initiate evasive action once it becomes apparent that a motor vehicle is going to enter the roadway. The authors believe that the following important questions must be answered before it is possible to recommend that bicyclists be taught to ride in the center of the traffic lane.

- Would riding in the center of the traffic lane increase the likelihood of detection by a margin that has practical significance?
- Would riding in the center of the traffic lane increase the bicyclist's preview time by a margin that has practical significance?
- How would traffic efficiency be affected if riding in the center of the traffic lane became a common practice?
- Should riding in the center of the traffic lane be prohibited on some types of roadways and/or during certain time periods? If so, what types of roadways and what time periods?
- Should young bicyclists and/or slow-moving bicycles be permitted to ride in the center of the traffic lane? If not, what is the cutoff age/speed?

- Would riding in the center of the traffic lane increase the incidence of other types of bicycle/motor-vehicle accidents or the incidence of accidents involving two motor vehicles?

Motorists. An education and training program for motorists has the potential for reducing the incidence of most problem types within Class C. The main objective of an education program would be to increase the effectiveness with which motorists search when entering uncontrolled roadways from driveways or from a controlled leg of an intersection. It is particularly important to modify the typical search patterns of motorists such that they make a concerted effort to scan for wrong-way bicyclists and for bicyclists riding on the sidewalk. When designing a training program for motorists, care must be taken to avoid promoting wrong-way riding. For instance, motorist-training materials developed for presentation on public television--and therefore observed by both motorists and bicyclists--should always include a message that stresses the danger and illegality of wrong-way riding.

Regulations and Enforcement

A portion of Problem Types 8 and 9 involved a bicyclist who was riding on the sidewalk prior to the collision. Furthermore, it was found that sidewalk accidents occurred most frequently when the bicyclist was riding in a direction opposite to that of motor-vehicle traffic in the adjacent traffic lane. These findings suggest that the incidence of Class C accidents may be reduced by establishing regulations that would prohibit sidewalk riding altogether or that would permit sidewalk riding only when the bicyclist is riding in the same direction as traffic in the adjacent traffic lane. Before recommending such regulation, however, it would be necessary to obtain clear evidence that the overall incidence of accidents would not be increased by forcing all bicyclists to ride in the roadway. For instance, it is altogether possible that prohibition of sidewalk riding would result in an increased number of accidents involving very small children.

Riding facing traffic is presently unlawful throughout the entire United States, so there is no need to establish regulations covering this unsafe practice. However, there is a serious need to increase the enforcement of this law and to increase the penalty associated with its violation. Riding facing traffic is one of a relatively small number of violations that frequently result in bicycle/motor-vehicle accidents. For this reason, it seems reasonable to establish a selective enforcement program in which law enforcement officers are required to *always* issue citations to bicyclists who are observed riding facing traffic (along with a few other critical violations). If officers are to be induced to issue citations to bicyclists who ride facing traffic, they must be convinced of the dangers associated with this violation. Therefore, the first step in implementing an effective enforcement program would be to inform law enforcement officers of the types of accidents that result from wrong-way riding, the frequency with which such accidents occur, and the reasons for which they occur. Although issuing citations to bicyclists is one of the most distasteful aspects of most enforcement officers' jobs, it is believed that officers would take the trouble to enforce the bicycle laws that are known to be critical for safety.

CLASS D PROBLEM TYPES

Class D includes five problem types that occurred when (a) a vehicle overtook and collided with a bicyclist traveling in the same direction, or (b) the threat of an overtaking motor vehicle caused the bicyclist to collide with an object that obstructed the path he would have taken if the obstruction had not been present. Class D does *not* include cases in which the bicyclist turned or swerved into the path of an overtaking motor vehicle.

Table 36 lists the problem types and subtypes for Class D and shows the proportion of fatal and non-fatal cases that were classified into each problem type and subtype. It can be seen in Table 36 that Class D accounted for nearly 38% of all fatal cases and that nearly one-fourth of all fatal accidents were classified into Problem Type 13. Since Class D accounted

TABLE 36

PROBLEM CLASS D--MOTORIST OVERTAKING/OVERTAKING-THREAT

		SUBTYPE		TYPE	
		FATAL	NON-FATAL	FATAL (N=166)	NON-FATAL (N=753)
TYPE 13	MOTORIST OVERTAKING: BICYCLIST NOT OBSERVED			24.6%	4.0%
	■ RURAL NIGHTTIME	9.0%	1.3%		
	■ RURAL DAYTIME	5.4%	.4%		
	■ URBAN NIGHTTIME	8.4%	1.3%		
	■ URBAN DAYTIME	1.8%	1.0%		
TYPE 14	MOTORIST OVERTAKING: MOTOR VEHICLE OUT OF CONTROL			4.2%	.7%
TYPE 15	MOTORIST OVERTAKING: COUNTERACTIVE EVASIVE ACTION			2.4%	1.7%
TYPE 16	MOTORIST OVERTAKING: MOTORIST MISJUDGED SPACE REQUIRED TO PASS			1.8%	2.0%
TYPE 17	MOTORIST OVERTAKING: BICYCLIST'S PATH OBSTRUCTED			.6%	2.0%
	■ BICYCLIST COLLIDED WITH OVERTAKING MOTOR VEHICLE	.6%	.8%		
	■ BICYCLIST COLLIDED WITH OBSTRUCTING OBJECT	---	.4%		
	■ BICYCLIST COLLIDED WITH OPENING MOTOR-VEHICLE DOOR	---	.8%		
TYPE UNKNOWN	MOTORIST OVERTAKING: TYPE UNKNOWN			4.2%	.1%
TOTAL CLASS (N: FATAL = 63; NON-FATAL = 79)		25.2%	6.0%	37.8%	10.5%

for only 10.5% of the non-fatal cases, it is clear that the likelihood of suffering fatal injuries is far higher for Class D accidents than for any other accident class. The high incidence of fatal injuries is mainly the result of the high speed of the motor vehicle on impact. About 45% of both the fatal and non-fatal accidents in Class D occurred in a rural area. It also was found that 56% of all rural accidents in the fatal sample and 31% of the rural accidents in the non-fatal sample were classified into Class D.

PROBLEM-TYPE DESCRIPTIONS

Problem Type 13 (24.6% Fatal; 4.0% Non-Fatal)

Although seven other problem types occurred more frequently[16] than Problem Type 13, this problem type must be considered one of the most important, because it accounted for nearly one-fourth of all fatal accidents in the sample--three times as many as any other problem type. Because of the large number of fatal cases in Problem Type 13, Appendix D-3 contains a Data Summary Sheet for both the fatal and non-fatal cases classified into this problem type. An examination of the two Data Summary Sheets will show that the data for the fatal and non-fatal cases are highly similar in nearly every respect. In the following discussion of Problem Type 13, the percentage values that are cited refer only to the non-fatal sample. When the values cited for the non-fatal sample are not equally representative for the fatal sample, the differences are described and discussed in the text.

The distinguishing characteristic of Problem Type 13 is that the operator of the overtaking motor vehicle failed to observe the bicyclist until the vehicles were in such close proximity that successful evasive action was impossible. Fifty percent of the non-fatal accidents and 59% of the fatal accidents of this type occurred in a rural area. About three-fifths of the rural accidents and about one-half of the urban accidents occurred on a narrow, two-lane roadway with no ridable shoulder. Thus,

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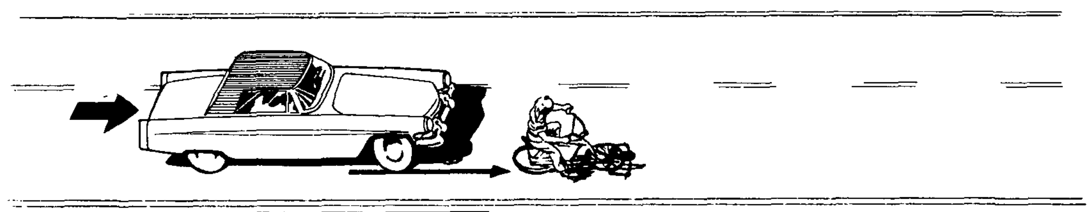
[16]Weighted combination of fatal and non-fatal accidents.

about 60% of the Type 13 accidents occurred on a narrow, "rural type" roadway with two traffic lanes and no ridable shoulder or sidewalk. This type of context is depicted in the illustration of Problem Type 13 (see Figure 38).

Problem Type 13 is the only problem type for which nighttime accidents were more frequent than daytime accidents. It was found that 63% of the non-fatal accidents and 71% of the fatal accidents occurred during darkness.

The exact position of the bicyclist and motorist at impact was difficult to determine with sufficient precision to know whether the bicyclist was traveling too far to the left or the motorist was traveling too far to the right. In about 20% of the cases, it was clearly established that the motorist was traveling farther to the right than he should have been. In the remaining cases, neither the motorist's position nor the bicyclist's position was judged to be clearly abnormal; it is probable that both operators were slightly out of position when the collision occurred.

The interviews revealed that bicyclists tend to ride farther from the right-hand edge of the roadway during darkness than during the daytime. Because of the combined effects of darkness and inefficiency of the bicycle headlight (if any), bicyclists are unable to detect and dodge road-surface defects and debris that often are present along the extreme edge of the roadway. To avoid such hazards, bicyclists ride farther to the left where the roadway is usually swept clean by the draft of motor-



FATAL = 24.6%
NON-FATAL = 4.0%

Figure 38. Illustration of Problem Type 13, *Motorist Overtaking: Bicyclist Not Observed.*

vehicle traffic. Because of this practice, it is probable that most of the bicyclists involved in nighttime accidents on narrow roads were riding farther to the left than is safe on such roadways.

Since Problem Type 13 included only the overtaking accidents in which the motorist failed to observe the bicyclist until too late to avoid the accident, the main question about this problem type concerns the reasons for the motorist's failure to observe the bicyclist. In nearly every case, the motorist's failure to observe the bicyclist was the result of one or more of the following factors: darkness, inadequate bicycle lighting, alcohol use by the motorist, and operator distractions. Since vehicle speeds are usually considerably faster on rural than urban roadways, the type location can also be considered a contributing factor for this problem type. The reasons for the motorist's failure to search can be most meaningfully described by subdividing Problem Type 13 into the following subtypes:

- Rural nighttime (9% fatal; 1.3% non-fatal). For this subtype, the motorist's failure to observe the bicyclist must be explained in terms of the relatively high speed of the motor vehicle, darkness, inadequate bicycle lighting, and alcohol use by the motorist. It is interesting to note that one-third of the fatal accidents of this type involved a motorist who had been drinking; none of the non-fatal accidents involved an intoxicated motorist.

- Rural daytime (5.4% fatal; .4% non-fatal). The motorist's failure to observe the bicyclist must be explained in terms of high motor-vehicle speeds, alcohol use by the motorist, and search failures by the motorist due to momentary distractions. Again, it is of interest to note that one-third of the fatal cases, but none of the non-fatal cases involved an intoxicated motorist.

- Urban nighttime (8.4% fatal; 1.3% non-fatal). The factors contributing to the motorist's failure to search in this situation are essentially the same as for rural nighttime accidents, except that high motor-vehicle speed is not a factor. Like rural nighttime accidents, urban nighttime accidents often involved alcohol use by the motorist. An intoxicated motorist was involved in 43% of the fatal cases and eight percent of the non-fatal cases.

- Urban daytime (1.8% fatal; 1.0% non-fatal). This subtype occurred so infrequently that it is not possible to draw valid inferences about the motorist's failure to search. However, it is almost certain that the motorist's attention was temporarily distracted from the roadway ahead shortly before the collision.

The above findings can be summarized by saying that it is dangerous to ride in rural areas at any time and it is dangerous to ride during darkness at any location, but accident likelihood is greatly increased when riding in a rural area during darkness.

It is interesting to note that about 60% of the bicyclists who were involved in nighttime accidents had lawful taillights on their bicycles when the accident occurred. This finding suggests that the standards that have been established for bicycle rear reflectors are inadequate under some circumstances. In establishing standards for taillights, the question is not how far away a motorist can observe the rear reflectors under optimal conditions, but what is required to attract a motorist's attention under non-optimal conditions. For instance, What type of taillight would be required to attract the attention of a fatigued drunk driver who is traveling at a relatively high speed on a rural roadway where he does not expect to encounter a bicyclist? It is probable that this type of accident will continue to occur until a device is developed that will increase the nighttime conspicuity of the bicycle to such an extent that the previously described motorist will detect and identify the bicyclist most of the time.

Few young bicyclists are involved in Type 13 accidents. For example, it was found that the age of the 5th centile bicyclist in the fatal and non-fatal samples was 12.9 and 11.2 years, respectively. Apparently, bicyclists younger than 11 or 12 years of age are not permitted to ride during darkness and in the types of areas where Type 13 accidents occur. The median age was 18.3 years for the bicyclists in the non-fatal sample and 20.5 years for bicyclists in the fatal sample.

Problem Type 14 (4.2% Fatal; .7% Non-Fatal)

Problem Type 14 includes overtaking accidents that occurred because the motorist was unable to maintain control of his vehicle. The illustration of Problem Type 14, shown in Figure 39, is somewhat misleading in its suggestion that the motor vehicle was in an uncontrolled slide or spin prior to the collision. Although the motor vehicle was totally out of

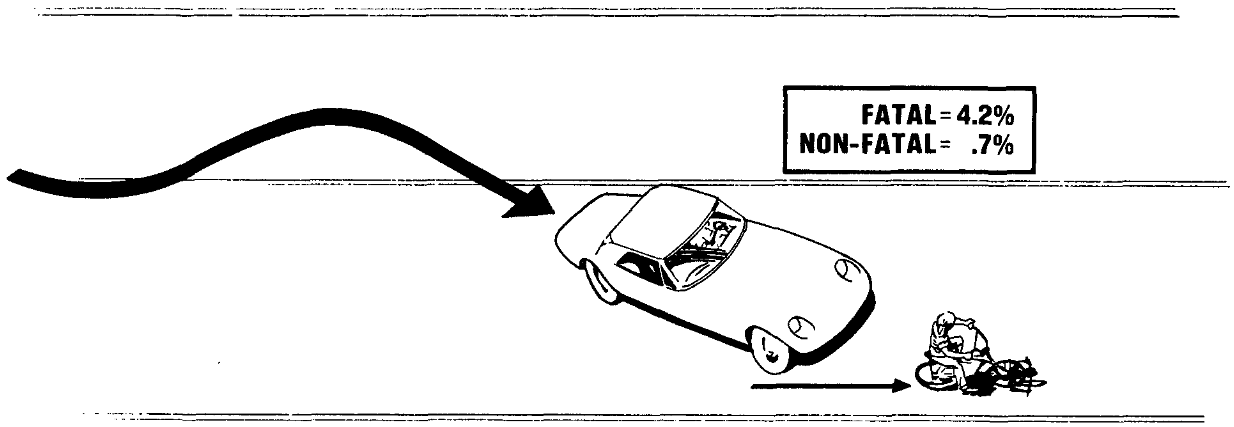


Figure 39. Illustration of Problem Type 14, *Motorist Overtaking: Motor Vehicle Out of Control.*

control in some cases, more often the motor vehicle veered too far to the right due to the motorist's inability to maintain precise control of the vehicle.

Alcohol use by the motorist was the main contributing factor in 71% of the fatal cases and 40% of the non-fatal cases. In these cases, it was judged that the motorist's capability was impaired to such an extent that he was unable to steer the vehicle along his intended path. These accidents would have occurred whether or not the bicyclist had been observed by the motorist. In the remaining cases, loss of control was due to vehicle failure, snow and ice on the roadway, or a prior collision with another motor vehicle. It might be expected that accidents of this type would occur most often on narrow roadways where the space is marginally adequate for both motor vehicles and bicycles. However, it was found that 86% of the fatal cases and 100% of the non-fatal cases occurred on an urban street with more than two traffic lanes. Although the preponderance of accidents on wide roadways may be an artifact due to the small number of Type 14 accidents in the sample, it seems safe to conclude that limited roadway width is not an important contributing factor for Problem Type 14. Twenty-nine percent of the fatal accidents and 40% of the non-fatal accidents occurred during darkness, but degraded visibility was not judged to be a contributing factor. The higher incidence of Type 14 accidents during darkness is simply because the number of intoxicated motorists on the roadway is greater at night than during the daytime.

The number of cases classified into Problem Type 14 is too small to define a bicyclist target group, but it seems reasonable to conclude that involvement in this type of accident would be totally independent of the age of the bicyclist. The small number of bicyclists involved in this type of accident varied in age from six to 17 years.

Problem Type 15 (2.4% Fatal; 1.7% Non-Fatal)

Problem Type 15 includes overtaking accidents that resulted from both operators misjudging the direction of the other operator's evasive action. In the typical case, the motorist observed the bicyclist ahead, riding close to the center of the traffic lane. As the motorist approached the bicyclist from the rear, he honked his horn and swerved left to pass the bicyclist. Upon hearing the horn (or the sound of the overtaking motor vehicle in some cases), the bicyclist evaded to the left with the assumption that the motor vehicle was going to pass on the right. In short, the bicyclist's evasive action counteracted the evasive action taken by the motorist. Although Figure 40 shows both operators evading to the left, there were some accidents of this type that occurred when both operators evaded to the right.

More than three-fourths of the accidents of this type occurred in a rural area on a two-lane roadway (52%) or a roadway with more than two

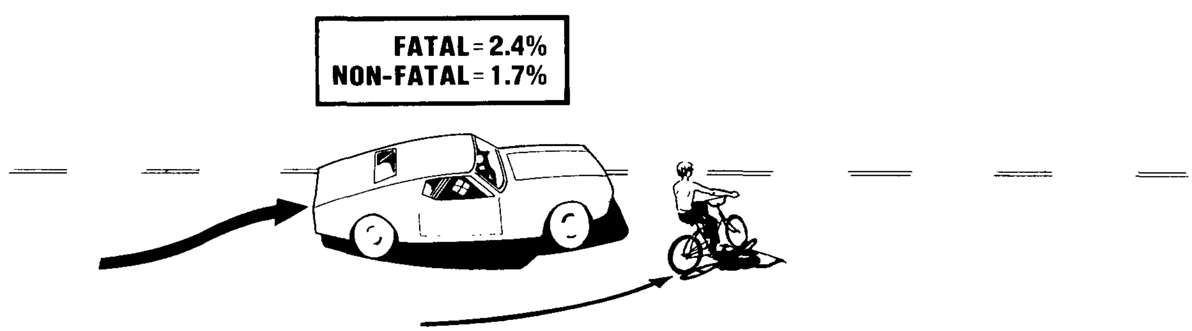


Figure 40. Illustration of Problem Type 15, *Motorist Overtaking: Counteractive Evasive Action.*

lanes (25%). The remaining 23% of the accidents occurred on a two-lane urban street. All accidents classified into Problem Type 15 occurred during the daytime between noon and 8:00 PM.

This type of accident usually involved a juvenile bicyclist. The median age of the bicyclists was 12.3 years, and fewer than five percent were older than 16 years of age. Slightly over five percent of the bicyclists were younger than six years of age.

Problem Type 16 (1.8% Fatal; 2.0% Non-Fatal)

An overtaking accident was classified into Problem Type 16 only when there was clear evidence that the accident resulted from the motorist's misjudgment of the space required to overtake and pass the bicyclist. As is shown in Figure 41, the bicyclist usually was struck by the extreme right-front portion of the motor vehicle. In 13% of the cases, the motorist misjudged the space and time required to scan behind and change lanes before closing on the bicyclist riding ahead. These accidents could easily have been avoided if the motorist had slowed his speed before scanning behind to determine if it was safe to change lanes. In the remaining cases, the motorist observed the bicyclist ahead and incorrectly concluded that there was sufficient space to overtake and pass the bicyclist without changing lanes. In some cases, the motorist was temporarily prevented from changing lanes; in other cases, the motorist could have changed lanes but did not deem it necessary to do so.

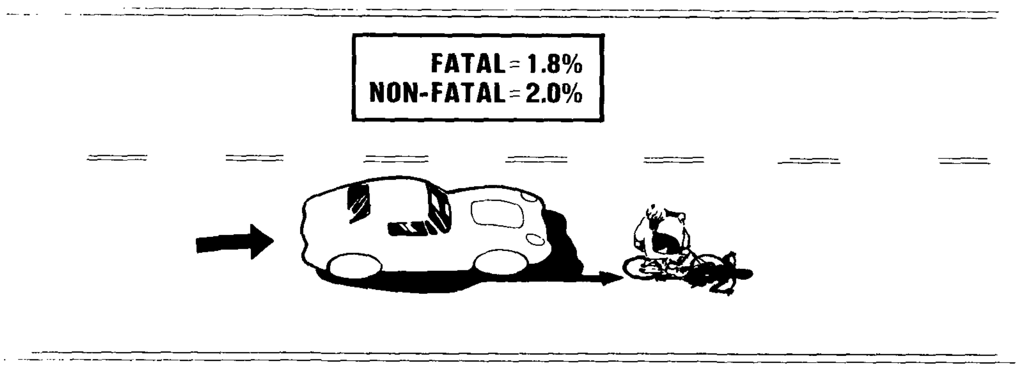


Figure 41. Illustration of Problem Type 16, *Motorist Overtaking: Motorist Misjudged Space Required to Pass.*

Type 16 accidents occurred on a variety of roadways, including: an urban two-lane street (29%), an urban street with more than two lanes (29%), a rural two-lane roadway (29%), and a rural roadway with more than two lanes (13%). All Type 16 accidents occurred during the daytime.

The age of the bicyclists involved in Type 16 accidents varied widely. The median age of the bicyclists for this problem type was 15 years; about five percent were younger than nine years of age and five percent were older than 42 years of age. Older motorists are clearly over-represented in this problem type. It was found that 25% of the motorists were older than 66 years of age and five percent were older than 86 years of age.

Problem Type 17 (.6% Fatal; 2.0% Non-Fatal)

The distinguishing characteristic of Problem Type 17 is that the bicyclist was confronted simultaneously with the threat of an overtaking motor vehicle and an object that obstructed the path that he otherwise would have followed. Reference to Figure 42 shows that the bicyclist in this situation sometimes collided with the overtaking motor vehicle and sometimes collided with the obstructing object. In 40% of the cases, the bicyclist collided with the overtaking motor vehicle while swerving

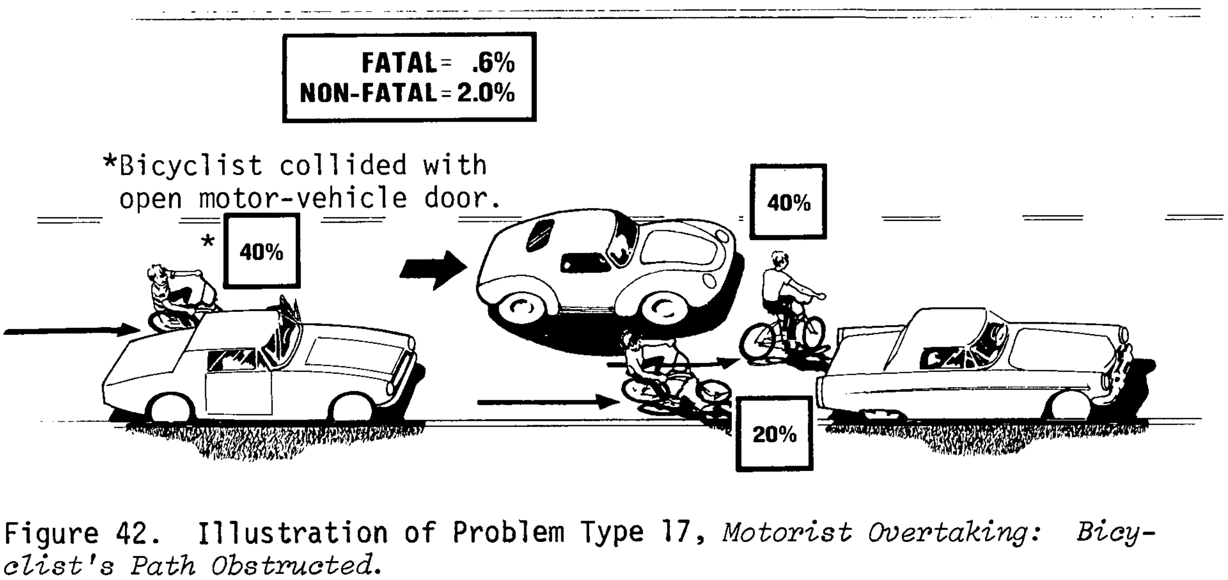


Figure 42. Illustration of Problem Type 17, *Motorist Overtaking: Bicyclist's Path Obstructed.*

around an obstruction in his path (parked motor vehicle, roadway defect, pole, etc.). The motorist in these accidents observed the bicyclist but misjudged the magnitude of the bicyclist's turn to the left. In 20% of the cases, the bicyclist collided with the rear of a parked motor vehicle that obstructed his path. Many accidents involving a parked motor vehicle probably go unreported.

Forty percent of the Type 17 accidents occurred when the occupant of a parallel-parked motor vehicle opened the left-hand door into the bicyclist's path. Although some motorists reported that they searched to the rear for traffic, none observed the bicyclist prior to the collision. Similarly, the bicyclist failed to observe that the parked motor vehicle was occupied. The relative frequency with which bicycles collide with an opening motor-vehicle door may be higher in some areas than was found in this study. In an unreported study by the authors of 931 traffic accident report forms from areas within five different states, it was found that car-door-opening accidents accounted for 2.6% of all reported bicycle/motor-vehicle accidents. However, the frequency with which this type of accident occurs was found to vary widely from one area to another. For instance, in a sample of 220 reports from Washington, D. C., it was found that 6.4% of all reported bicycle/motor-vehicle accidents were car-door-opening accidents. Conversely, not a single car-door-opening accident was found among a sample of 184 bicycle/motor-vehicle accidents that occurred in Fairfax County--an area located only a few miles from Washington, D. C. Based upon the information presently available, it is estimated that car-door-opening accidents account for between two and four percent of the accidents that occur in urban areas. The percentage would probably be highest in the central business districts where the number and turnover of parallel-parked motor vehicles is high.

Most Type 17 accidents occur in urban areas; 57% occur on an urban two-lane street and 29% on an urban street with more than two lanes. Only 14% occurred on a rural roadway. All accidents of this type occurred during the daytime.

Surprisingly, few very young bicyclists were involved in this type of accident. The median age of the bicyclists was 16.3 years; only five percent were younger than nine years of age. The interquartile range for Problem Type 17 accidents was 12.9 years to 23.2 years.

Motorist Overtaking, Type Unknown (4.2% Fatal; .1% Non-Fatal)

In 4.2% of the fatal cases and .1% of the non-fatal cases, the information on the traffic accident report form was sufficient to establish that the accident was an overtaking accident but was not sufficient to determine the motorist's function failure and, therefore, the specific problem type into which the case should be classified. About half of the accidents occurred at night and about half occurred in rural areas. From the information that was available for these accidents, it is probable that most of them would have been classified into Problem Type 13. If this assumption is correct, the proportion shown in Table 36 for fatal accidents represents an underestimate of the frequency with which Type 13 fatal accidents occur.

COUNTERMEASURE APPROACHES FOR CLASS D PROBLEM TYPES

Environmental Changes

The fear of overtaking accidents and the assumption that this type of accident occurs with great frequency are among the main reasons why on-street bicycle lanes have been so appealing to persons concerned with bicycle safety. Judging from the types of locations where on-street bicycle lanes have been constructed in the past, it appears that decisions about the need for bicycle lanes have been based on the assumption that overtaking accidents most often occur on narrow roadways that carry heavy bicycle and motor-vehicle traffic and have many motor vehicles parked along them.

The fear of overtaking accidents is well founded since the likelihood of fatal injuries is indeed higher for overtaking accidents than for any other class of accidents revealed by this study. However, the data reported here show that accidents of this type occur far less frequently than many persons assume and, more importantly, they seldom occur in the types of dangerous-*appearing* locations in which bicycle lanes most often have been constructed in the past. Apparently, areas that appear dangerous to bicycle-facility planners also appear dangerous to bicyclists and motorists. Because both operators perceive such areas as dangerous, they exercise more caution than under ordinary circumstances and thereby offset the obvious threat imposed by the traffic context.

Except for accidents that resulted from the motor vehicle being out of control, it seems reasonable to assume that most Class D accidents would not have occurred if an on-street bicycle lane had been present and the bicyclist had been riding in it. However, the problem in recommending on-street bicycle lanes as a countermeasure stems from the cost-effectiveness of this approach. First, consider that 46% of the fatal and 44% of the non-fatal overtaking accidents occurred in a rural area where bicycle traffic tends to be low and where it would be necessary to widen the paved area in order to accommodate an on-street bicycle lane. Because of the high cost associated with widening many miles of rural roadways and because of the relatively small number of bicyclists who would benefit from these facilities, it appears that the construction cost would far outweigh the combined benefits of accident reduction and increased riding pleasure. The same general problem exists in urban areas, even though the urban street might be wide enough to accommodate an on-street bicycle lane if parking was prohibited. That is, the inconvenience created by prohibiting parking on large numbers of urban streets would outweigh the benefit unless, of course, specific areas could be located where the likelihood of overtaking accidents is unusually high. Since these data did not reveal a distinct target area for urban overtaking accidents, it would be necessary to define high-risk areas--if they exist--through the study of accident records for each community.

It was stated earlier that on-street bicycle lanes may serve as a "buffer zone" that would serve to decrease the likelihood of some types of bicycle rideout accidents (Class A). It is also possible that the "buffer zone" provided by on-street bicycle lanes would reduce the incidence of accidents in which a bicyclist suddenly turns left into the path of an overtaking motor vehicle (Problem Type 18). Consequently, although a reduction in overtaking accidents may not be sufficient justification for the widespread use of on-street bicycle lanes, it is possible that their cost could be justified when considering all the problem types that might be positively affected by such facilities.

There is virtually no doubt that off-street bicycle lanes would reduce the incidence of overtaking accidents, if such facilities were available and used by bicyclists who otherwise would be riding on roadways. The obvious problem with off-street bicycle lanes is their high cost and the lack of space in most communities for constructing a comprehensive network of off-street bicycle lanes. There are many good reasons for constructing off-street bicycle lanes, but it is unlikely that the funding and space available in most communities would be sufficient to construct a network of bicycle lanes that would be comprehensive enough to have a significant impact on the incidence of overtaking accidents.

Many accidents occurred on a rural roadway that had no shoulder whatsoever. This finding suggests that the incidence of overtaking accidents on such roadways could be decreased by providing a shoulder that bicyclists could ride on. Although the cost of constructing a graded shoulder would be far less than the cost of constructing a paved bicycle lane adjacent to the roadway, it is unlikely that a substantial portion of bicyclists would ride on an unpaved shoulder. Bicyclists who ride lightweight bicycles are reluctant to ride on unpaved surfaces because the bicycle's stability and efficiency are reduced and because of the debris often encountered in such areas. These problems are compounded during darkness--when the likelihood of overtaking accidents is greatest--because the bicycle's headlight is so weak that bicyclists would find it extremely difficult to detect road-surface defects and debris during darkness. So, in the authors' opinion, providing unpaved shoulders would not be an effective countermeasure for overtaking accidents that occur in rural areas.

In summary, it seems certain that bicycle facilities (on-street bicycle lanes, off-street bicycle lanes, and paved shoulders) have the potential for reducing the incidence of Class D accidents if the facilities are constructed at the types of locations where such accidents occur and if bicyclists can be induced to use the facilities. It is also possible that bicycle facilities would effect a reduction in other types of accidents as well. However, there are many reasons to doubt that it would be cost-effective to construct bicycle facilities at the types of locations where Class D accidents occur.

Bicycle Modifications

Problem Type 13, more than any other problem type revealed by this study, points to the need for increasing the nighttime conspicuity of the bicycle. Since more than one-half of the nighttime overtaking accidents involved bicycles that were equipped with rear-lighting equipment that met the current lighting standards, it is clear that existing lighting standards are not rigid enough to ensure the bicyclist's detection and identification in the types of traffic contexts in which nighttime overtaking accidents occur. If a rear lighting system is to be effective in avoiding accidents of this type, it must ensure the detection and identification of bicyclists by motorists who may be intoxicated, fatigued, drowsy, or a combination of these; may be driving on a narrow rural roadway at a speed as high as 55 MPH; and may have a low expectation of encountering a bicycle at that time and location. Furthermore, an acceptable lighting system must be relatively inexpensive, light in weight, impervious to vibration and exposure to the elements, theft proof, and power efficient--requiring infrequent replacement of the power source. The development of a rear-lighting system that would meet these specifications represents a difficult challenge for the engineering community. Electronic engineers suggest that an ideal system would involve the use of one or more high-intensity strobe lights powered by a battery that is recharged automatically by a solar cell mounted on the bicycle. Obviously, the feasibility of such a system would depend upon its cost.

It was stated earlier that many bicyclists are reluctant to ride too far to the right-hand edge of the roadway during darkness because the front light does not illuminate the path well enough for them to avoid road-surface defects and debris along the extreme edge of the roadway. For this reason, more effective front-lighting equipment may reduce the incidence of nighttime overtaking accidents by enabling bicyclists to ride farther to the right-hand edge of the roadway.

For some years, there has been talk of developing anti-collision warning devices that would provide a warning signal when a motor vehicle is on a collision course with another vehicle or object. The cost of such devices could not be justified on the basis of bicycle/motor-vehicle accidents alone. However, if such systems were developed and installed in all motor vehicles as a general-purpose anti-collision warning system, it may be cost-effective to equip bicycles with a transponder that would activate the warning signal and thereby alert motorists that they are overtaking a bicyclist.

Motor-Vehicle Modifications

In a small, but significant, number of overtaking accidents, the bicyclist was struck by the right-hand side mirror of a truck or recreational vehicle. This finding suggests the need to develop right-hand mirrors that would protrude less far from the vehicle or would be located high enough off the ground to pass over the head of a bicyclist. The value of breakaway mirrors is questionable because it is unlikely that a breakaway mirror could be developed that would withstand wind resistance at high speeds and yet break away with a force low enough to avoid seriously injuring a bicyclist.

Education and Training

Bicyclists. With only a few exceptions, there is little that a bicyclist can be taught that would help him avoid Class D accidents once he has decided to ride where and when such accidents are most likely to occur. As a consequence, the primary objective of an education and training program for bicyclists should center on modifying the bicyclist's choice of where and when he will ride. Until more effective rear-lighting systems are available, bicyclists should be taught to minimize the amount of night riding they do on any type of roadway, particularly night riding on rural roadways. Bicyclists must also be taught to be highly selective in choosing the type of rural roadways they will ride on, regardless of the lighting conditions that prevail at the time of their trip. Specifically, bicyclists should be taught to avoid riding on any type of rural roadway unless operating speeds are low and a ridable shoulder is present.

Ideally, bicyclists could be taught to monitor overtaking motor vehicles using a rear-vision device and to always evade to the shoulder when overtaking motor vehicles are observed. Although most overtaking accidents in rural areas would be avoided if bicyclists could be induced to follow this procedure, it is unrealistic to expect them to do so as a common practice. Such a procedure would become so tiresome that all the pleasure would be lost from bicycle touring.

Bicyclists must be taught to recognize situations in which the space is so limited that a motorist's misjudgment of the width of his vehicle might result in an overtaking accident. In some instances, the bicyclist can slow his speed enough that the motor vehicle and bicycle do not arrive at a bottleneck at the same moment. When traffic is heavy and the lateral space is limited for some distance, little can be done other than to avoid riding in such areas. Similarly, bicyclists should receive special instructions on how to behave when they must ride to the left of objects that obstruct the path along the right-hand edge of the roadway. When the street is narrow and there are many parked cars along its length, bicyclists should be taught to search the parked cars for occupants who may open the left-hand door of the parked motor vehicle.

In some instances, it may be safer to ride in the center of the traffic lane than to attempt to anticipate an opening motor-vehicle door. However, as was stated earlier, considerable study is required before recommending that bicyclists be taught to ride in the center of the traffic lane.

Bicyclists' parents. The objective of parental education would be to induce parents to prohibit their children from riding their bicycles in rural areas at any time, during darkness in any location, and on any type of roadway on which operating speeds are high and space is limited. Essentially, the parents should receive the same type of education as the bicyclists.

Motorists. It is unlikely that any type of training would increase the likelihood that motorists will observe bicyclists under the circumstances in which Type 13 accidents occur. However, it is possible that motorist training would serve to decrease the incidence of accidents that result from a motorist's misjudgment of the space required to overtake and pass a bicyclist and accidents that occur when a motorist opens the left-hand door of his motor vehicle into the path of a bicyclist.

Regulations and Enforcement

Until truly effective rear-lighting systems can be developed, the most certain way of preventing nighttime overtaking accidents is to prohibit nighttime riding in the areas where this type of accident is most likely to occur. The data compiled during the course of this study are insufficient to develop specific criteria that local officials can use to define the types of roadways on which night riding should be prohibited. It is almost certain that the most critical variables are operating speed, motor-vehicle traffic volume, bicycle-traffic volume, number of traffic lanes, traffic-lane width, availability and type of shoulder, availability of sidewalks adjacent to the roadway, and street lighting. However, a fairly large and comprehensive study would be required to determine the combination of these variables that would be most predictive of nighttime overtaking accidents.

Existing regulations concerning the rear-lighting requirements for bicycles should be rewritten to acknowledge that lawful lighting equipment does not ensure the bicyclist's safety in some traffic contexts. When and if more effective rear-lighting systems are developed, the regulations should be rewritten to require the use of the new equipment on all bicycles that are ridden at night.

The likelihood of all rural overtaking accidents would probably be decreased by decreasing the speed limit on the rural roadways on which bicyclists often ride. However, it is unlikely that the research required to identify such roadways could be conducted by every community throughout the country. It is also unlikely that such a solution would be politically feasible in light of the relative infrequency with which this type of accident occurs.

A relatively small number of accidents occurred when the bicyclist was in the center of the roadway preparing to make a left-hand turn. However, the number was large enough to justify regulations prohibiting left-hand turns from the center of the roadway at night. Even with a highly efficient rear-lighting system, motorists would sometimes find it impossible to detect and evade a slow-moving or stopped bicyclist in the middle of the roadway preparing to make a left turn. During darkness, the bicyclist should be required to stop at the right-hand edge of the roadway, check for oncoming traffic, and ride or walk in a path perpendicular to the roadway. This procedure would expose the rotating wheel reflector and reflectorized tires to the headlights of approaching motor vehicles.

Although there is a clear need for more effective rear-lighting equipment, the equipment now required by law is far more effective than none at all. Therefore, the existing laws governing lighting equipment should be rigidly enforced. The serious consequences of nighttime overtaking accidents easily justify the immediate impoundment of bicycles that are ridden at night without lawful lighting equipment.

CLASS E PROBLEM TYPES

All the accident cases classified into Problem Class E occurred when a bicyclist--suddenly and without warning--turned or swerved into the path of an overtaking motor vehicle or a motor vehicle approaching from directly ahead of the bicyclist. The cases within Class E were classified into four problem types that together accounted for 16.2% of the fatal cases and 14.2% of the non-fatal cases. Table 37 lists the descriptive titles for the Class E problem types and shows the proportion of fatal and non-fatal cases classified into each problem type.

PROBLEM-TYPE DESCRIPTIONS

Problem Type 18 (8.4% Fatal; 8.4% Non-Fatal)

Problem Type 18 is one of the most important problem types, both in terms of frequency of occurrence and injury severity. Every Type 18 accident occurred when a bicyclist suddenly turned left into the path of an overtaking motor vehicle. About one-half of the bicyclists turned left at the junction of a roadway or driveway, and the remaining bicyclists initiated their turn at a point that was *not* in close proximity to any type of junction. (This finding is illustrated by the two sets of vehicles shown in Figure 43.) Problem Type 18 does not include cases in which the bicyclist lost control of his bicycle and inadvertently swerved left.

About one-half of the accidents occurred on a two-lane urban street and about 30% occurred on a two-lane rural roadway. The remaining 20%

TABLE 37

PROBLEM CLASS E--BICYCLIST UNEXPECTED TURN/SWERVE

		FATAL (N=166)	NON-FATAL (N=753)
TYPE 18	BICYCLIST UNEXPECTED LEFT TURN: PARALLEL PATHS, SAME DIRECTION	8.4%	8.4%
TYPE 19	BICYCLIST UNEXPECTED LEFT TURN: PARALLEL PATHS, FACING APPROACH	3.0%	3.2%
TYPE 20	BICYCLIST UNEXPECTED SWERVE LEFT: PARALLEL PATHS, SAME DIRECTION (UNOBSTRUCTED PATH)	3.6%	1.5%
TYPE 21	WRONG-WAY BICYCLIST TURNS RIGHT: PARALLEL PATHS	1.2%	1.1%
TOTAL CLASS (N: FATAL = 27; NON-FATAL = 107)		16.2%	14.2%

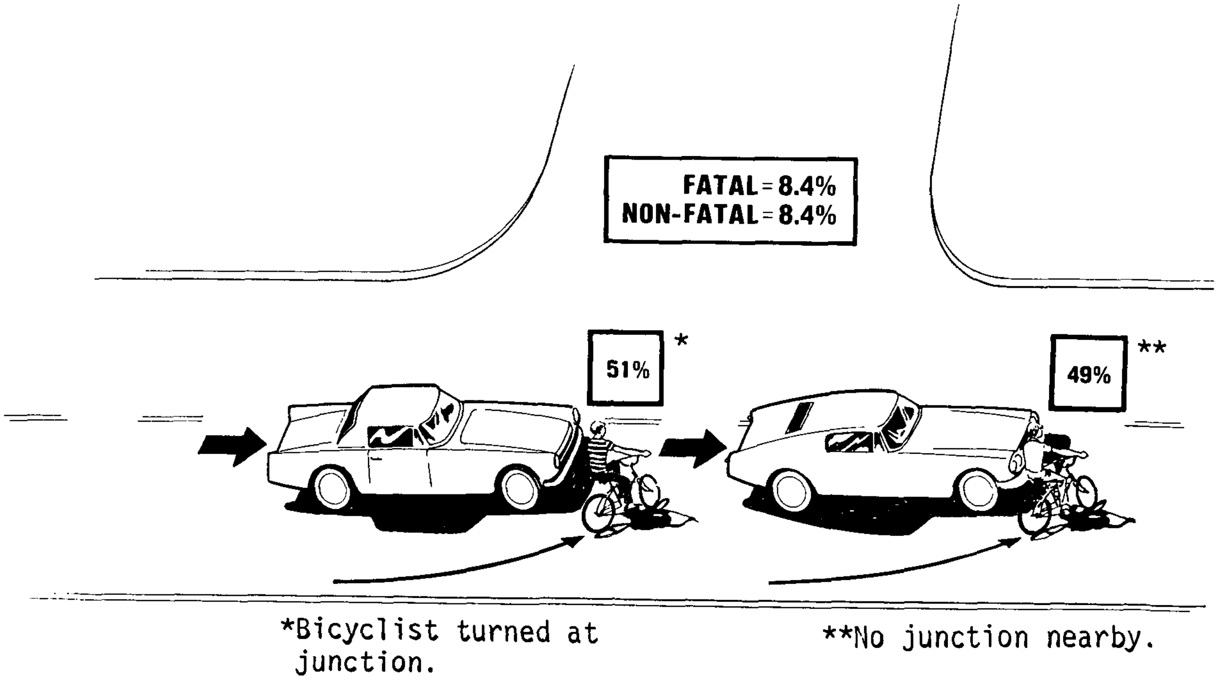


Figure 43. Illustration of Problem Type 18, *Bicyclist Unexpected Left Turn: Parallel Paths, Same Direction*

occurred with about equal frequency on urban and rural roadways with more than two lanes. Only seven percent of the fatal and two percent of the non-fatal accidents occurred during darkness, so degraded visibility is seldom a factor in accidents of this type. The apparent reason for the low incidence of nighttime accidents is that bicyclists can detect the headlights of overtaking motor vehicles without searching to the rear.

In 92% of the cases, it was judged that the motorist observed the bicyclist far enough in advance to have easily avoided the accident. The motorist failed to initiate any type of evasive action because he had no idea that the bicyclist intended to turn. A search failure by the motorist was found in slightly less than five percent of the cases. Conversely, a search failure by the bicyclist was evident in 94% of the cases. In the remaining six percent of the cases, the bicyclist was aware of the overtaking motor vehicle but incorrectly assumed there was sufficient time to cross the roadway before the approaching motor vehicle arrived.

It was known from pilot studies that accidents of this type occur frequently, so the Field Investigators were instructed to make a special attempt to determine *why* bicyclists fail to search behind before initiating a left turn. Although the interviews revealed a variety of different factors that may have contributed to the bicyclist's failure to search (see Appendix D-3), the authors believe that the most important contributing factors simply were not revealed by the interviews. Knowledge of the locations at which Type 18 accidents typically occur and informal discussions with many different bicyclists have led the authors to the tentative conclusion that bicyclists often fail to search behind because they assume an overtaking motor vehicle can be heard if it is near enough to pose a threat. Some accidents may occur because the sound of the overtaking motor vehicle is masked by other auditory stimuli. Wind noise, conversations with riding companions, and the noise generated by motor vehicles approaching in the opposing lane are examples of common noises that may serve to mask the sound of an overtaking motor vehicle. The interview data indicated that other accidents may occur when a bicyclist hears an overtaking motor vehicle but misjudges its proximity or its approach velocity. However, whether the sound of the overtaking motor vehicle is masked or misinterpreted, the fundamental error is a total reliance on auditory cues.

The authors believe that a secondary factor contributing to the bicyclist's failure to search concerns the degree of skill and effort required to search 180 degrees to the rear while maintaining lateral control of the bicycle. Searching to the rear without losing control of the bicycle is difficult under the best of circumstances, but is even more difficult when the bicyclist must simultaneously rotate the head and tilt it forward as is required when riding a bicycle with dropped handlebars. When riding a bicycle with dropped handlebars, many bicyclists look *under* their left arm when searching to the rear. This action requires the head to be tilted down about 90 degrees from vertical and rotated about 45 degrees to the left. Consequently, when searching to the rear, the vestibular mechanism is placed in a highly unusual position, and the signals from the vestibular system are equally unusual. Pilots of high-performance aircraft know that placing the head in an unusual position (tilting and/or rotating) while undergoing even moderate "g" forces creates unusual vestibular signals that, in turn, cause instant vertigo. It is hypothesized that bicyclists experience the same type of problems as aircraft pilots, only less severe.

In summary, it is believed that bicyclists are reluctant to search behind because it is difficult to do so. The reluctance to search behind has led bicyclists to rely on auditory cues to detect overtaking motor vehicles whenever possible. When bicyclists are traveling a roadway with heavy and continuous traffic, they recognize the necessity to search behind before turning left. However, when traveling a roadway with light and/or sporadic traffic, they believe that auditory cues are adequate to detect overtaking motor vehicles and consider it safe to turn left when they fail to hear the sound of a nearby motor vehicle. Although auditory cues are reliable in most situations, there are some circumstances in which the sound of the overtaking motor vehicle is masked or distorted. It is in these situations that bicyclists turn left into the path of an overtaking motor vehicle.

In about six percent of the Type 18 accidents, the bicyclist did search to the rear before turning but failed to observe the overtaking motor vehicle or misjudged its speed. In several cases, the motor vehicle that collided with the bicyclist was masked from view by another motor vehicle. The bicyclist searched behind and observed the lead vehicle, searched in a forward direction until it had passed, and turned into the path of the second (trailing) motor vehicle.

At least three percent of the Type 18 accidents resulted from one bicyclist "blindly" following another. The lead bicyclist searched to the rear and correctly judged that he had enough time to turn left and clear the roadway before an overtaking motor vehicle arrived. Without searching to the rear, the trailing bicyclist followed the lead bicyclist--assuming that it was safe to turn. Although the trailing bicyclist turned shortly after the lead bicyclist initiated his turn, the lag time was great enough to place the trailing bicyclist on a collision course with the overtaking motor vehicle. Because bicyclists may be reluctant to admit that they were blindly following a lead bicyclist, it is probable that this behavior was a factor in more Type 18 accidents than was revealed by the interview data.

Most of the bicyclists who were involved in Type 18 accidents were juveniles. The median age of the bicyclists was 12.7 years; five percent of the bicyclists were younger than seven years of age, and 75% were 14 years of age or younger.

Problem Type 19 (3.0% Fatal; 3.2% Non-Fatal)

Like Problem Type 18, Problem Type 19 includes cases in which the bicyclist suddenly turned left into the path of the motorist. However, Problem Type 19 includes only the cases in which the bicyclist turned into the path of a motor vehicle approaching from straight ahead. Functionally, the most important differences between Problem Types 18 and 19 are the ease with which bicyclists can perform a search for the approaching motor vehicle (straight ahead vs. straight behind) and the amount of time the motorist has to respond once the bicyclist initiates his left-hand turn.

Although it might be assumed that Type 19 accidents would occur most often on busy multiple-lane roadways, it was found that only 17% of the cases occurred on a roadway with more than two lanes. The remaining cases occurred on either a two-lane urban roadway (58%) or a two-lane rural roadway (25%). It was found that 96% of the accidents classified into Problem Type 19 occurred during the daytime.

Figure 44 shows that only three-fourths of the bicyclists initiated their left-hand turn at a point that was in close proximity to a roadway or driveway junction. In the remaining cases, there was no junction of any kind near the point at which the bicyclist initiated his turn. The bicyclists in Figure 44 are shown turning from a point clost to the right-hand edge of the roadway. Although such turns were most typical, the data

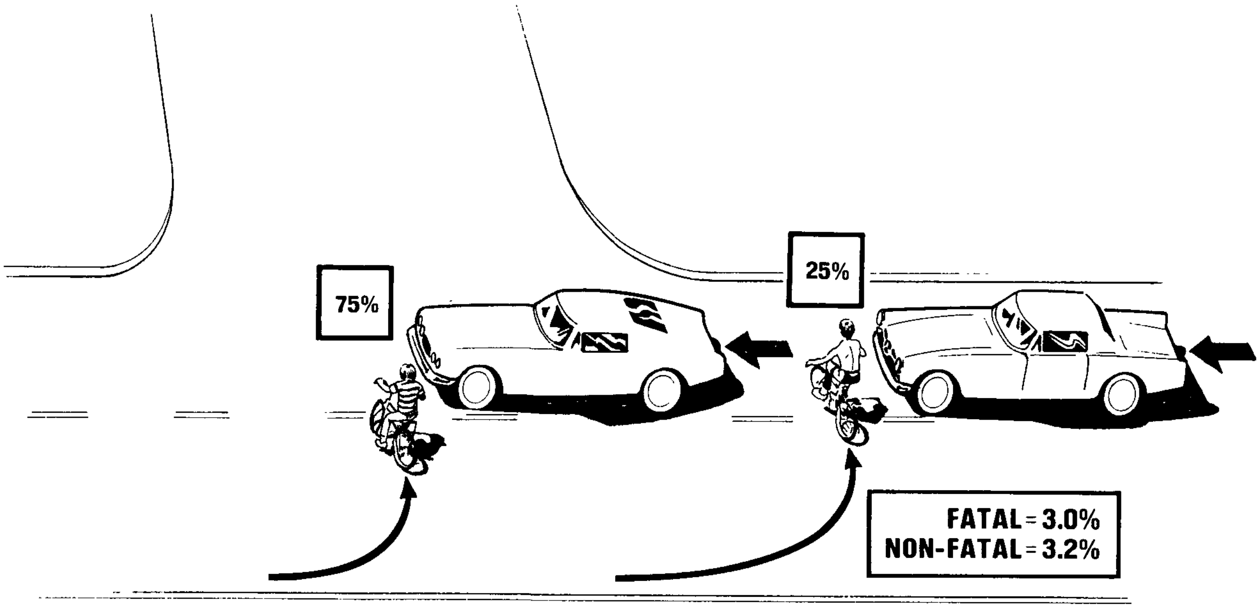


Figure 44. Illustration of Problem Type 19, *Bicyclist Unexpected Left Turn: Parallel Paths, Facing Approach.*
(NOTE: Most, but not all, bicyclists initiated their left-hand turn at a point close to the right-hand edge of the roadway.)

showed that about 29% of the bicyclists initiated their turn from a point close to the center of the roadway. Contrary to expectations, the bicyclists who were riding close to the center of the roadway prior to initiating their turn were *not* riding on a multiple-lane roadway.

Despite the fact that the motor vehicle was approaching from directly ahead and was clearly visible to the bicyclist, it was found that at least 75% of the bicyclists failed to search in the direction of the motor vehicle until an accident was imminent. The proportion of search failures would probably have been higher, but the bicyclist's function failure could not be confidently established in 12% of the cases. Surprisingly, not a single case was found in which the bicyclist observed the motor vehicle but misjudged its approach velocity. The bicyclist's search failure was most often due to operator distractions. The types of distractions that most often contributed to the bicyclist's search failure include: interacting with riding companion (41%), vehicles/pedestrians considered an accident threat (24%), and game playing (12%). In another 12% of the cases, it was found that the bicyclist's failure to search was due to his faulty assumption that a riding companion would search for hazards and select a safe course.

About 70% of the motorists observed the bicyclist before he initiated his turn. Because of the narrowness of the roadway and the bicyclist's high-angle turn, it was judged that only about 10% of the motorists who were searching in the bicyclist's direction had sufficient time for evasive action once the bicyclist initiated his turn. These motorists failed to initiate evasive action because they assumed the bicyclist would slow or stop before entering the motor vehicle's path. Twelve percent of the motorists failed to search in the direction of the bicyclist. In eight percent of the cases, the motorist's view of the bicyclist was temporarily obstructed by a moving vehicle.

Knowledge of the bicyclist's behavior in this situation would suggest that Type 19 accidents would most often involve very young bicyclists. Although young bicyclists were most frequently involved, half the bicyclists were older than 13 years of age and 25% were older than 18 years of age. The median age of the bicyclists was 13.8 years and five percent were younger than seven years of age.

Problem Type 20 (3.6% Fatal; 1.5% Non-Fatal)

Problem Type 20 includes accidents in which the bicyclist inadvertently swerved left and collided with an overtaking motor vehicle. Figure 45 shows the bicyclist swerving into the path of an overtaking motor vehicle, but some bicyclists swerved into the side of the motor vehicle. Accidents of this type occurred on urban two-lane streets (46%), urban streets with more than two lanes (27%), and on rural two-lane roadways (27%). Every case classified into Problem Type 20 occurred during the daytime.

The most frequent reason for the bicyclist's inadvertent swerve was a prior collision with a curb (25%) or another bicycle (17%). Vehicle failures, operator skill deficiencies, and roadway-surface defects were each found to be a contributing factor in about 17% of the cases. In

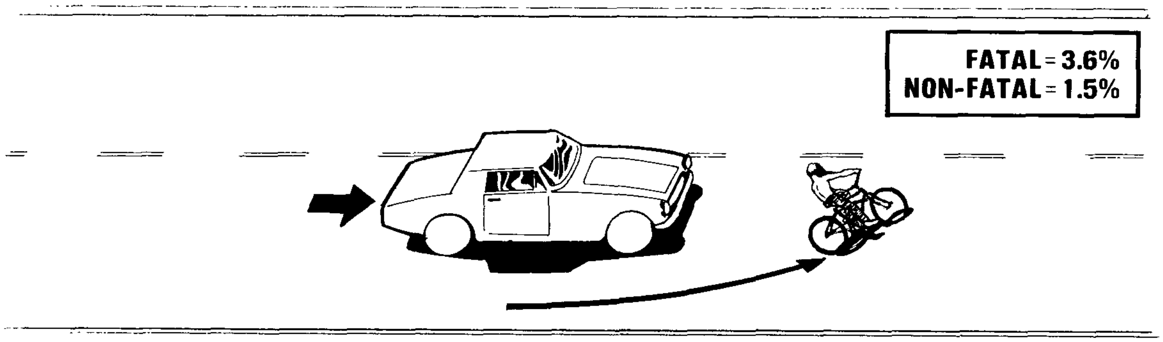


Figure 45. Illustration of Problem Type 20, *Bicyclist Unexpected Swerve Left: Parallel Paths, Same Direction (Unobstructed Path).*

nearly every case, the motorist observed the bicyclist well in advance but had insufficient time to avoid the accident once the bicyclist swerved.

Accidents of this type seldom involved adult bicyclists. The median age of the bicyclists for Problem Type 20 was 11.5 years. Only five percent of the bicyclists were older than 17 years of age; 75% of the bicyclists were between 8.5 and 15.1 years of age.

Problem Type 21 (1.2% Fatal; 1.1% Non-Fatal)

Problem Type 21 includes accidents in which a bicyclist who had been riding facing traffic suddenly initiated a right-hand turn into the path of an approaching motor vehicle. Figure 46 shows the bicyclist turning into the path of a motor vehicle approaching from the opposite direction.

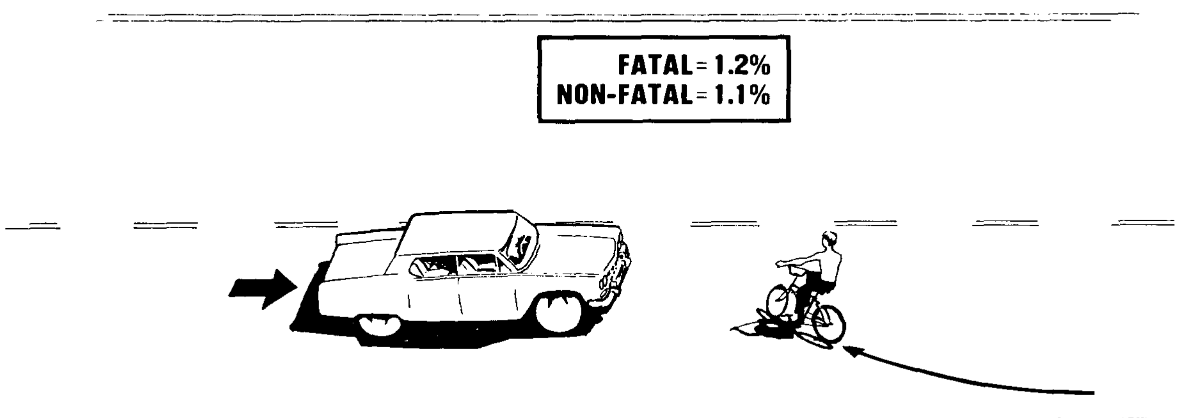


Figure 46. Illustration of Problem Type 21, *Wrong-Way Bicyclist Turns Right: Parallel Paths.*

Although most accidents occurred in this way, Problem Type 21 also includes accidents in which the bicyclist crossed the first half of the roadway and collided with an overtaking motor vehicle in the second half. However, only one case was found that occurred in this manner. Seventy-five percent of the accidents occurred on a two-lane urban street, and all Type 21 accidents occurred during the daytime.

In one case, it was found that the bicyclist's view of the oncoming motor vehicle was obstructed by a parked vehicle. In the remaining cases, the bicyclist failed to search in the motorist's direction because of a momentary distraction. In most cases, the bicyclist was distracted by another person with whom he was riding (57%). Other distractors contributing to the bicyclist's search failure include abnormal functioning of the bicycle (14%), riding an unfamiliar bicycle (14%), and riding a bicycle that was too large for the bicyclist (14%).

Except for the one case in which the bicyclist emerged suddenly from behind a parked motor vehicle, the motorist observed the bicyclist soon enough to have avoided the accident if he had been able to anticipate the bicyclist's intention to turn.

The bicyclists involved in Problem Type 21 varied in age from seven to 13 years. The sample was too small to obtain a reliable estimate of the centiles.

COUNTERMEASURE APPROACHES FOR CLASS E PROBLEM TYPES

Environmental Changes

One of the most obvious countermeasure approaches suggested by the study of Class E accidents is the construction of barriers that would prevent bicyclists from turning across a traffic lane except at selected locations. At the locations where turns are permitted, the path could be routed such that the bicyclist would be traveling perpendicular to the roadway at the entry point, thereby eliminating the requirement to search to the rear in order to check for approaching traffic. Although this solution might be practical at a few locations, its widespread application would be enormously expensive. More importantly, barriers would create many operational problems for motor-vehicle traffic. For instance, the construction of barriers throughout an entire block would deny motorists access to intersecting driveways and alleys. Providing an opening in the barrier at every driveway and alley junction would defeat the purpose of the barriers. Furthermore, the presence of barriers close to junctions would prevent motorists from merging to the right-hand curb in preparation for a right-hand turn. Requiring motor vehicles to turn right from a traffic lane would disrupt the flow of traffic and would probably increase the number of motor-vehicle accidents as well.

It was suggested earlier that the presence of a conventional on-street bicycle lane (marked with a line) would provide a "buffer zone" that would increase the preview time of overtaking motorists. When a bicyclist suddenly initiates a left-hand turn into the path of an overtaking motor vehicle, it is uncertain whether an additional six or eight feet separating the paths of the two vehicles would provide the motorist with the additional preview time needed to initiate successful evasive action. However, it is probable that such a six- or eight-foot buffer zone would eliminate the accidents in which the bicyclist swerves into the path of the overtaking motor vehicle (Problem Type 21). In addition, a bicyclist might be more inclined to search behind for overtaking motor vehicles before initiating a turn if he knew that precise lateral control was not required. That is, if a bicyclist had from five to eight feet of protected space, he would know that the loss of lateral stability, which may occur when searching to the rear, would not cause him to veer into either a curb or the path of an overtaking motor vehicle.

Bicycle Modifications

A clear majority of Class E accidents involved a bicyclist who turned left into the path of an *overtaking* motor vehicle and, with only a few exceptions, the bicyclist failed to search behind or signal before initiating his turn. Earlier, it was hypothesized that bicyclists are reluctant to search to the rear because of the fear they will fall, veer into a curb or off the roadway, or veer into the path of an overtaking motor vehicle. It was further hypothesized that the reluctance to search to the rear has led bicyclists to rely on auditory cues to detect overtaking motor vehicles. If further research shows these hypotheses to be valid, one potentially effective countermeasure approach is to provide bicyclists with rear-vision devices that would enable them to search to the rear without having to rotate their head and torso.

One type of rear-vision device that has been endorsed by many bicyclists is a small mirror that is mounted to eyeglass frames or on a helmet. Although some expert bicyclists claim that head-mounted mirrors are difficult to use and may represent a safety hazard for the bicyclist's eye, other experts claim that these problems can easily be overcome. The most difficult problem with head-mounted mirrors is getting the target population to use the device each time they ride their bicycle. The authors believe that it would be extremely difficult to induce juveniles to install the mirror on their eyeglasses or to wear a helmet with a rear-vision device attached each time they choose to ride their bicycle. It may be nearly as difficult to induce adults to always use such devices.

An alternative to the head-mounted mirror is a mirror that is permanently mounted on the bicycle. Although bicycle-mounted mirrors have not been evaluated systematically, discussions with expert bicyclists indicate that the field of view of most mirrors is too limited to be of value and that the vibration is usually so great that it is impossible to interpret the image that appears in the mirror. Wide-angle mirrors do not represent a feasible solution because they reduce the size of the imagery to such an extent that distance judgments are nearly impossible. That is, the small size of a motor vehicle's image in the mirror leads one to assume that the motor vehicle is farther away than it actually is. Because of the potential value of an effective rear-vision device, it appears that the research required to develop a truly effective rear-vision device is warranted. To be effective, it will probably be necessary to develop a device that is permanently mounted on the bicycle and that damps out the vibration. In addition, such a device would have to be extremely rugged and yet constructed in a manner that would not cause injuries in the event of an accident.

Education and Training

Bicyclists. A study of Class E accidents suggests two types of education and training for bicyclists. First, education and training is needed to increase the bicyclist's propensity to search--both ahead and to the rear--and to signal prior to turning across the roadway. An important part of this training involves convincing bicyclists that auditory cues alone are not sufficient to signal the presence of an overtaking motor vehicle. Specifically, bicyclists should be taught that they should be alert to auditory cues but not to assume the absence of a motor vehicle because one cannot be heard. Because distractions often contributed to the bicyclist's search failure, bicyclists should be taught the importance of momentary distractors and how to overcome them.

It is possible that the bicyclist's reluctance to scan to the rear can be overcome by training. Expert bicyclists claim that, through proper training, bicyclists can become quite proficient at scanning to the rear without veering. However, before such training is introduced on a large-scale basis, it would be necessary to conduct research to determine the type of training that is best and the extent to which proficiency at this task can be increased through training the target population for Class E accidents.

Finally, when effective rear-vision devices become available, bicyclists should be taught how and when to use such devices.

Motorists. It is possible that some benefit would be derived from an education and training program designed to inform motorists of the frequency with which Class E accidents occur and to modify motorists' assumptions that a bicyclist will search and signal before initiating his turn. Certainly, motorists should be taught to give the bicyclist as wide a berth as possible when overtaking and passing. However, because of the suddenness of the bicyclist's turn, it is unlikely that such training would result in a substantial decrease in accidents of this type.

Regulations and Enforcement

The study of Class E accidents indicates that failing to signal before turning is an important violation that should be rigidly enforced. It is interesting to note that not a single case was found in which the bicyclist signaled before turning. There are two possible explanations for this finding. First, it is possible that accident likelihood is reduced by the bicyclist's signal even though he fails to search effectively before initiating his turn. A second, and more probable, explanation is that bicyclists who are inclined to signal before turning are also inclined to search before turning. In either case, it is almost certain that enforcing the laws governing signaling would decrease the likelihood of Class E accidents. Whether the law should be expanded to require a specified search pattern is a question that must be answered by additional research.

CLASS F PROBLEM TYPES

Problem Class F includes accidents that occurred when a motorist turned into the path of a bicyclist approaching from the motorist's front or rear. In nearly every case, the motorist failed to observe the bicyclist before initiating his turn--usually because the bicyclist was riding in an unexpected location. In some cases, the bicyclist failed to observe the turning motor vehicle until the accident was imminent. In most cases, however, the bicyclist observed the motor vehicle and either failed to anticipate the motorist's turn or incorrectly assumed that the motorist would delay his turn until the intersection was clear. As is shown in Table 38, Problem Class F accounted for 2.4% of the fatal cases and 14.5% of the non-fatal cases. The three problem types within Class F differ in terms of the motorist's direction of turn and the bicyclist's position and direction of travel relative to that of the motorist.

TABLE 38

PROBLEM CLASS F--MOTORIST UNEXPECTED TURN

	FATAL (N=166)	NON-FATAL (N=753)
TYPE 22 MOTORIST UNEXPECTED LEFT TURN: PARALLEL PATHS, SAME DIRECTION	.6%	1.3%
TYPE 23 MOTORIST UNEXPECTED LEFT TURN: PARALLEL PATHS, FACING APPROACH	---	7.6%
TYPE 24 MOTORIST UNEXPECTED RIGHT TURN: PARALLEL PATHS	1.8%	5.6%
TOTAL CLASS (N: FATAL = 4; NON-FATAL = 109)	2.4%	14.5%

PROBLEM-TYPE DESCRIPTIONS

Problem Type 22 (.6% Fatal; 1.3% Non-Fatal)

Problem Type 22 includes accidents in which the motorist turned left into the path of a bicyclist approaching from the left-rear of the motor vehicle. Figure 47 shows that accidents of this type occurred in two distinctly different ways. In 60% of the cases, the bicyclist was traveling in the same direction and in the same lane as the motor vehicle. As the motor vehicle slowed in preparation for a left-hand turn, the bicyclist overtook and collided with the turning motor vehicle. In the remaining cases, the bicyclist was riding facing traffic along the left-hand edge of the roadway prior to the collision.

Twenty percent of the accidents of this type occurred on a two-lane rural roadway. The accidents that occurred in an urban area occurred with equal frequency on a two-lane street and on a street with more than two lanes. Although 30% of the accidents occurred during darkness, darkness was judged to be a contributing factor in only one case. In all other cases, the bicyclists were riding in a location that was not searched by the motorist. That is, it was judged that the accident would have occurred even if the lighting conditions had been optimal.

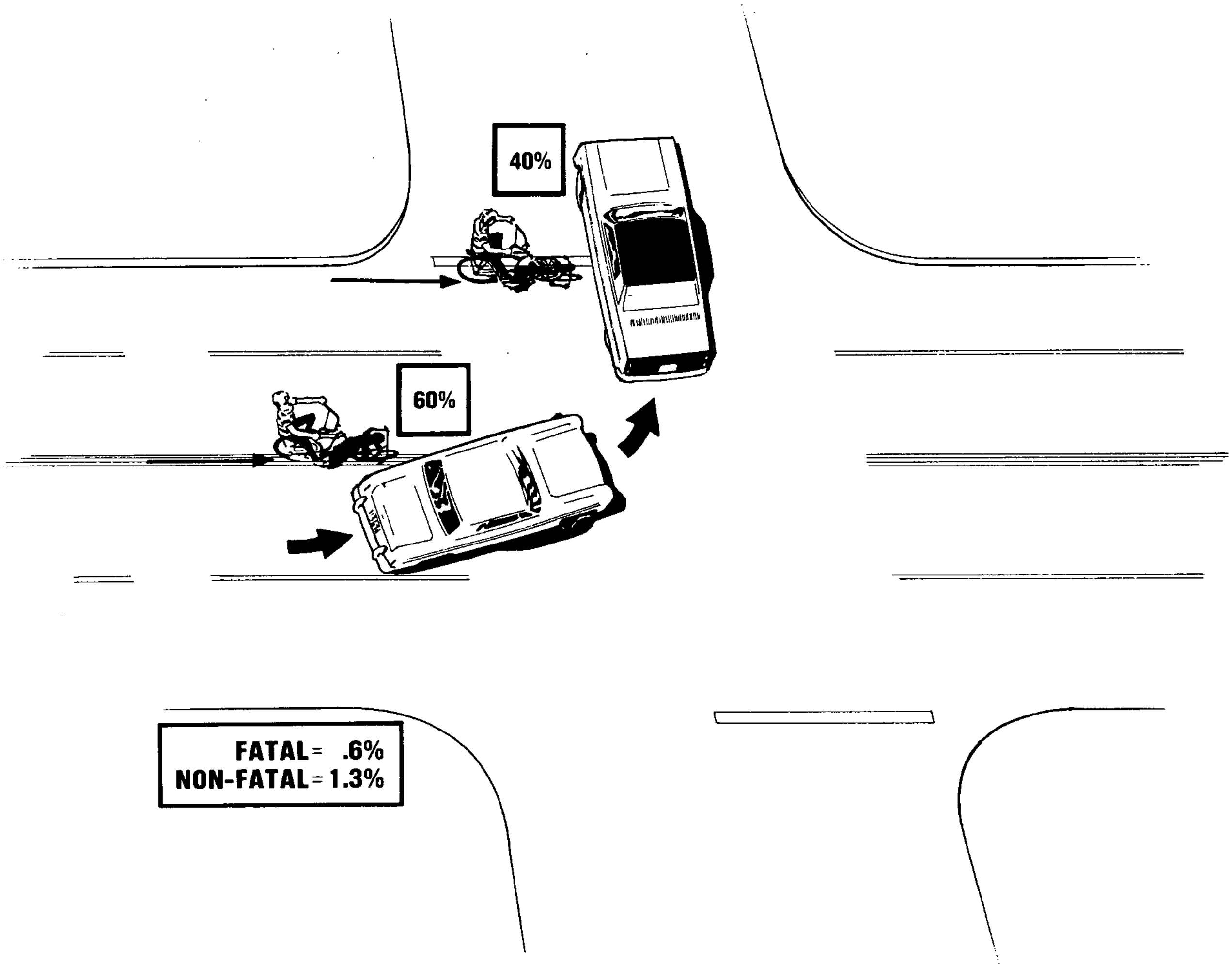


Figure 47. Illustration of Problem Type 22, *Motorist Unexpected Left Turn: Parallel Paths, Same Direction.*

In 90% of the cases, the motorist failed to search in the bicyclist's direction before initiating his turn because he simply did not expect a threat to be approaching from that direction. Thirty percent of the bicyclists also failed to search and consequently failed to observe the motor vehicle until it was too late to avoid the accident. All the search failures were committed by the wrong-way riding bicyclists. In the remaining cases, the bicyclist observed the motorist early enough to have avoided the accident. The bicyclist's failure to initiate evasive action upon observing the motor vehicle was due to his failure to anticipate the turn or his assumption that he had been detected by the motorist and that the motorist would yield to him.

The median age of the bicyclists involved in Type 22 accidents was 15.9 years, and fewer than five percent were younger than 12 years of age. Conversely, 25% of the bicyclists were older than 23.5 years of age.

Problem Type 23 (7.6% Non-Fatal; No Fatal)

Problem Type 23 includes cases in which the motorist turned left into the path of a bicyclist approaching from the opposite direction. Specific subtypes of Problem Type 23 are as follows:

- Intersection, bicyclist in street (68%),
- Intersection, bicyclist rode off sidewalk (7%),
- Driveway/alley junction, bicyclist in street (16%), and
- Driveway/alley junction, bicyclist on sidewalk (9%).

Only three problem types accounted for more non-fatal cases than Problem Type 23; yet, not a single Type 23 accident was found among the fatal sample. Figure 48 shows that 86% of the bicyclists were riding legally in the roadway prior to the accident; the remaining bicyclists had been riding on the sidewalk before entering the jucntion where the collision occurred.

Sixty percent of the accidents classified into Problem Type 23 occurred on an urban street with four or more lanes; 39% occurred on a two-lane urban street. Only four percent of the accidents occurred in a rural area. Accidents of this type occurred at a significant rate throughout the period between 6:00 AM and 11:00 PM; 13% of the accidents occurred during darkness.

The operator's view was obstructed by vegetation (bicyclist on sidewalk) or moving motor vehicles in only six percent of the cases, so visual obstructions clearly are not an important factor for this problem type. In nearly one-fifth of the cases, the motorist failed to observe the bicyclist because of degraded visibility conditions. In these cases, the motorist's visibility was degraded by one of the following: darkness (14%), sun glare (6%), or glare from artificial lights (2%). Of the bicyclists who went undetected by the motorist at night, one-half were equipped with an operational headlamp.

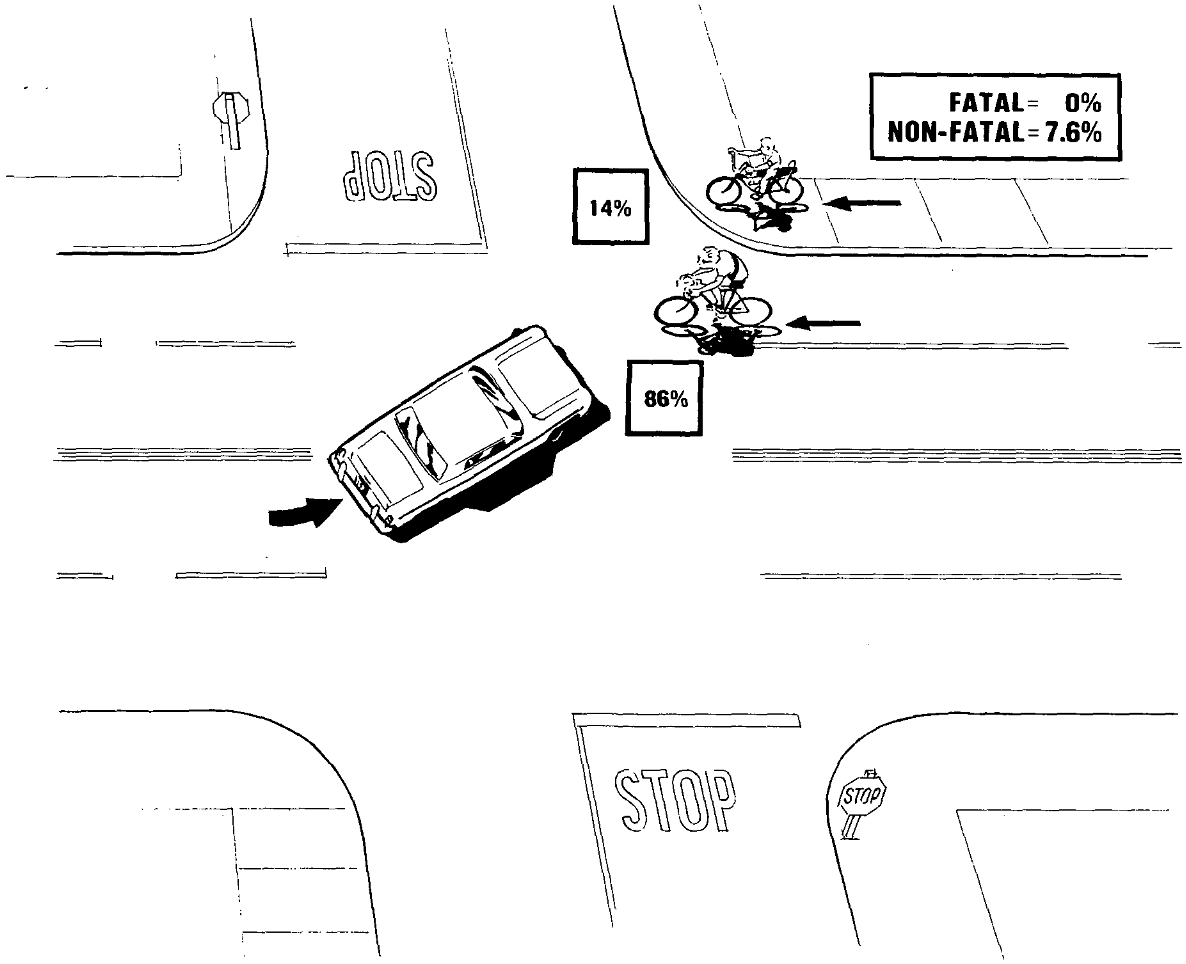


Figure 48. Illustration of Problem Type 23, *Motorist Unexpected Left Turn: Parallel Paths, Facing Approach.*

In 68% of the cases, the bicyclist was not observed by the motorist even though the motorist's view was unobstructed and the visibility conditions were good. Thirty-eight percent of the motorists reported that they scanned in the bicyclist's direction several times before turning but still failed to observe the bicyclist until the vehicles collided, or a moment before. It is probable that all the motorists who committed a search failure did, in fact, scan in the general direction of the bicyclist at least once. Thirty-six percent of the motorists reported that their search failure was at least partly due to distractions by vehicles or pedestrians that were considered an accident threat.

An examination of the traffic context in which Type 23 accidents occurred would lead one to expect that information overload may have often contributed to the motorist's search failure. Although the information was seldom sufficient to clearly establish the presence of information overload, an evaluation of the traffic context indicates that this may have been a factor in at least half the cases in which a search failure was identified.

Thirty percent of the bicyclists failed to search in the direction of the motor vehicle until it was too late to avoid the accident. The remaining bicyclists observed the motor vehicle but did not, or could not, initiate evasive action until the accident was imminent. Typical patterns of failures by the bicyclist are as follows:

- The bicyclist failed to search in the motorist's direction because he falsely assumed that all turning traffic would yield to him (30%).
- The bicyclist observed the motorist, correctly concluded that the motor vehicle was going to turn, but falsely assumed that he had been detected and that the motorist would yield (29%).
- The bicyclist observed the motor vehicle stopped in the center of the roadway waiting for an opportunity to turn. The bicyclist continued because he assumed that the motor vehicle would remain stopped until he had cleared the junction (24%).
- The bicyclist correctly concluded that the vehicles were on a collision course but was unable to avoid the collision because of a vehicle failure (wet or defective brakes) or a skill deficiency (9%).

It was found that the bicyclists involved in this type of accident were older than for any other problem type. The median age of the bicyclists was 20.1 years. Only 25% of the bicyclists were younger than 16 years of age, and only five percent were younger than 11 years of age.

Problem Type 24 (1.8% Fatal; 5.6% Non-Fatal)

The distinguishing characteristic of Problem Type 24 is that a motorist collided with an approaching bicyclist while in the process of making a right-hand turn. Figure 49 shows that 74% of the accidents involved a bicyclist who was approaching from the motorist's right rear.

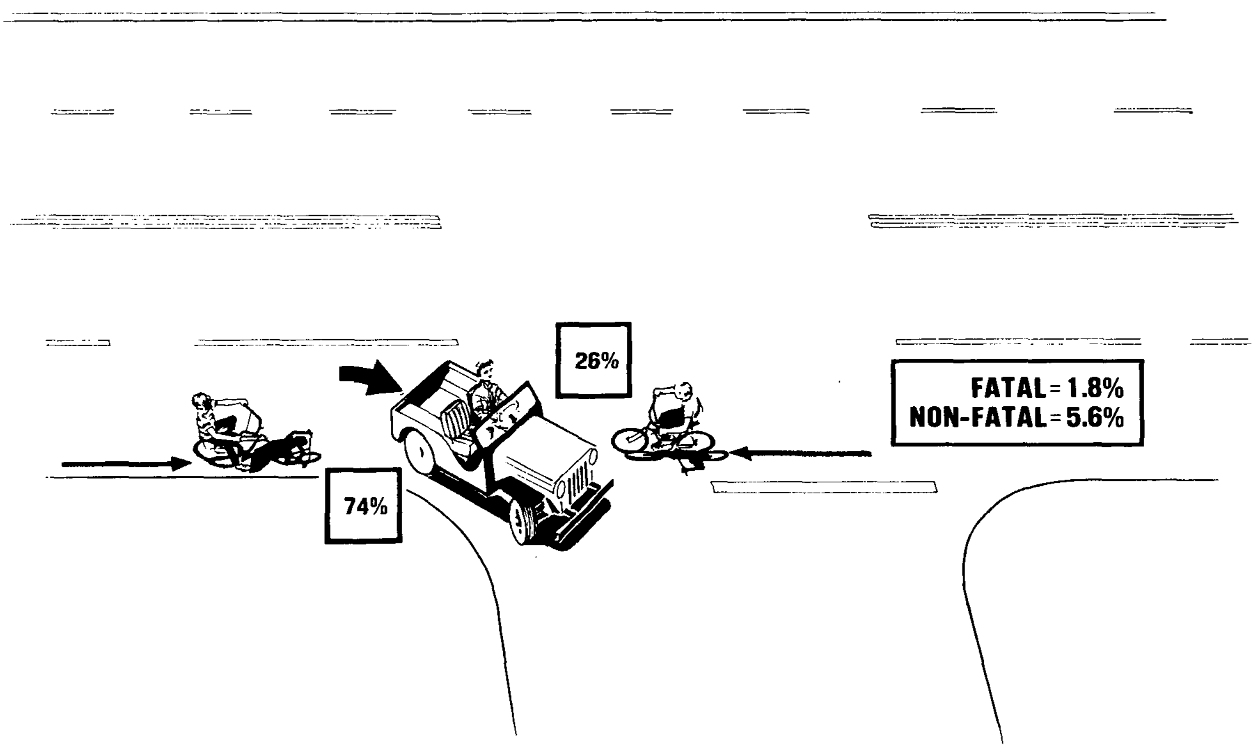


Figure 49. Illustration of Problem Type 24, *Motorist Unexpected Right Turn: Parallel Paths.*

This subtype typifies the classical right-turn accident that has been so widely publicized. In the remaining cases, the motorist turned into the path of a bicyclist approaching from straight ahead--riding facing traffic.

Every accident of this type occurred in an urban area. In 59% of the cases, the motorist was traveling on a two-lane urban street prior to the collision. In the remaining cases, the motorist was traveling on a street with more than two lanes. Most accidents occurred at either the junction of two roadways (64%) or the junction of a street and driveway (29%), but Problem Type 24 also included a small number of cases (7%) in which the motorist turned right to enter an on-street parking space. In most cases, the bicyclist was traveling on the same roadway as the motorist. However, in eight percent of the cases, the bicyclist entered the junction from a sidewalk. Ninety-five percent of the accidents occurred during the daytime; 83% occurred during the period between 11:00 AM and 6:00 PM.

More than 97% of the motorists reported that they failed to observe the approaching bicyclist at the time they initiated their right-hand turn. In about five percent of the cases, the motorist's view of the bicyclist approaching from the rear was obstructed. In about 93% of the cases, however, the bicyclist was clearly visible to the motorist but went undetected because the motorist failed to scan carefully in the bicyclist's direction. The most common reasons given for the motorist's failure to search in the bicyclist's direction include:

- Bicyclist in unusual/unexpected location (40%).
- Assumed bicyclist overtaken before turn was far behind and posed no threat (37%).
- Expected all traffic to yield or evade (13%).
- Motorist was momentarily distracted (13%).
- Motorist misjudged the speed of the approaching bicyclist (3%).

About 12% of the bicyclists failed to search in the motorist's direction--usually because of momentary distractions. The remaining bicyclists observed the motorist far in advance but failed to correctly evaluate the motorist's intentions. In 24% of the cases, the motor vehicle was stopped in a queue of motor vehicles when first observed by the bicyclist. As the bicyclist approached the junction at which the accident occurred, the queue of motor vehicles began moving, which enabled the motorist to move to the junction where he intended to turn right. The bicyclist either failed to anticipate the motorist's turn or assumed he could clear the junction before the motorist turned. Only one case of this type involved a wrong-way-riding bicyclist.

In about 64% of the cases, the bicyclist did not expect the motorist to turn, even though he observed the motor vehicle slow at the approach to the junction. In some cases the motorist failed to signal before turning. In other cases the motorist signaled but the bicyclist did not, or could not, see the signal. Because of conflicting testimony by the operators, it was impossible to estimate the number of cases in which: the motorist failed to signal, the bicyclist failed to observe a clearly visible signal, or the bicyclist was riding alongside the motor vehicle and could not see the motor-vehicle's turn-signal light. However, it is estimated that these three situations occurred with about equal frequency.

It was found that the bicyclists involved in accidents of this type varied widely in age. The median age was 16.8 years; about five percent of the bicyclists were 12 years of age or younger, and 25% were older than 22 years of age.

COUNTERMEASURE APPROACHES FOR CLASS F PROBLEM TYPES

Bicycle Modifications

The need to increase the daytime and nighttime conspicuity of the bicycle is further reinforced by the study of Type 23 accidents (motorist turns left into the path of bicyclist approaching from straight ahead). To decrease Type 23 accidents, devices must be developed to increase the bicycle's conspicuity when viewed from a front-oblique position.

Motor-Vehicle Modifications

The study of Problem Type 24 suggests the need for more effective rear-vision devices for motor vehicles. The mirrors on most motor vehicles are inadequate to detect a bicyclist located to the right-rear of the motor vehicle, particularly when the bicyclist is close enough to be partly obscured from view by a part of the motor-vehicle's structure. However, until motorists come to expect hazards to be approaching from the right-rear of their vehicles, it is unlikely that even the most effective rear-vision devices will result in a reduction in Type 24 accidents.

Type 24 accidents (motorist right-turn into the path of bicycle approaching from the right-rear) resulted in a relatively small number of fatal accidents, but nearly all of the fatalities resulted from the bicyclist being crushed by the right-rear wheels of a large truck. Because of the large distance between the ground and the bottom of the truck bed, it is very easy for a bicyclist to ride or fall under the truck bed where he is in a position to be run over by the right-rear wheel(s) of the truck.

These accidents suggest the need for a sheet metal skirt or, perhaps, nylon webbing to cover the large open space between the bottom of the truck bed and the ground.

Education and Training

Bicyclists. About one-third of all Class F accidents were the direct or indirect result of bicyclists riding in an unexpected location (excluding bicyclists approaching from the right-rear of the motorist). Thus, bicyclist education and training programs should be designed to curtail the following behavior:

- Wrong-way riding (14% of Class F),
- Entering a junction from a sidewalk (10% of Class F), and
- Overtaking and passing on the left of a motor vehicle at a junction (5% of Class F).

Whether or not bicyclists are riding in an expected location, they should be taught to search for motor vehicles that are in a position to turn (right or left) into their path. Although bicyclists should be taught to search for turn-signal lights and hand signals, they should also be taught that the lack of a signal does not necessarily mean that the motorist does not intend to turn. Bicyclists must be informed of the low conspicuity of the bicycle/bicyclist unit and taught to never assume that they have been observed by the motorist--even when the visibility conditions are good and the motorist scans in the bicyclist's direction. Finally, bicyclists must be informed of the dangers of overtaking and passing slow-moving or standing motor vehicles at junctions. Greatest emphasis should be placed on training to curtail passing on the right-hand side of slow-moving or standing motor vehicles.

Some bicycling experts believe that many Class F accidents would not occur if bicyclists were taught to ride in the center of the traffic lane rather than along the right-hand curb. They claim that riding in the center of the traffic lane would increase the likelihood that the bicyclist will be detected by the motorist and would eliminate the right-of-way conflicts with right-turning accidents. As was discussed earlier, a number of critical questions must be answered before recommending that bicyclists be taught to ride in the center of the traffic lane (see discussion of countermeasure approaches for Class E accidents).

Motorists. The main objective of a motorist education and training program is to modify motorist's search patterns in the traffic contexts where Class F accidents occur. An effective training and education program must increase motorist's expectations of encountering bicyclists and must teach them precisely where to search when preparing to make a left-hand or right-hand turn.

Enforcement

Increased enforcement of several critical violations by bicyclists has the potential for eliminating more than 40% of all Class F accidents. These violations include: wrong-way riding, overtaking and passing on the right at a junction, overtaking and passing on the left at a junction, and entering a junction from a sidewalk without slowing or stopping.

CLASS G PROBLEM TYPES

Class G includes the problem types that could not meaningfully be classified into any of the previously described classes (see Table 39). With the exception of Problem Types 25 and 26, the problem types within Class G occurred so infrequently that it was not possible to draw valid inferences about the nature of the accident-generation process. For this reason, Problem Types 27 through 36 are described in only enough detail to provide a general notion of how the accident occurred.

PROBLEM-TYPE DESCRIPTIONS

Problem Type 25 (.6% Fatal; 2.8% Non-Fatal)

Problem Type 25 includes cases in which (a) the collision occurred within an uncontrolled intersection and (b) the two vehicles approached on orthogonal legs of the intersection. Every case classified into Problem

TABLE 39

PROBLEM CLASS G--OTHER

		FATAL (N=166)	NON-FATAL (N=753)
TYPE 25	VEHICLES COLLIDE AT UNCONTROLLED INTER-SECTION: ORTHOGONAL PATHS	.6%	2.8%
TYPE 26	VEHICLES COLLIDE HEAD-ON, WRONG-WAY BICYCLIST	2.4%	3.6%
TYPE 27	BICYCLIST OVERTAKING	.6%	.9%
TYPE 28	HEAD-ON, WRONG-WAY MOTORIST	1.8%	.8%
TYPE 29	PARKING LOT, OTHER OPEN AREA: ORTHOGONAL PATHS	.6%	.8%
TYPE 30	HEAD-ON, COUNTERACTIVE EVASIVE ACTION	---	.1%
TYPE 31	BICYCLIST CUTS CORNER WHEN TURNING LEFT: ORTHOGONAL PATHS	.6%	---
TYPE 32	BICYCLIST SWINGS WIDE WHEN TURNING RIGHT: ORTHOGONAL PATHS	---	.3%
TYPE 33	MOTORIST CUTS CORNER WHEN TURNING LEFT: ORTHOGONAL PATHS	---	.4%
TYPE 34	MOTORIST SWINGS WIDE WHEN TURNING RIGHT: ORTHOGONAL PATHS	---	.1%
TYPE 35	MOTORIST DRIVEOUT FROM ON-STREET PARKING	---	.3%
TYPE 36	WEIRD	---	1.1%
-----	INSUFFICIENT INFORMATION TO CLASSIFY	7.2%	---
TOTAL CLASS (N: FATAL = 23; NON-FATAL = 84)		13.8%	11.2%

Type 25 occurred at the junction of a pair of two-lane roadways; 86% occurred in an urban area, and 14% occurred in a rural area. Figure 50 shows that a slight majority of the accidents of this type occurred in the second half of the roadway (57%). Although not illustrated in Figure 50, about 25% of the bicyclists were riding on the wrong side of the roadway prior to the collision. Ninety percent of the accidents occurred during the daytime when visibility conditions were near optimal.

Visual obstructions located close to the junction served to limit the motorist's preview time in 38% of the cases. Vegetation and parked motor

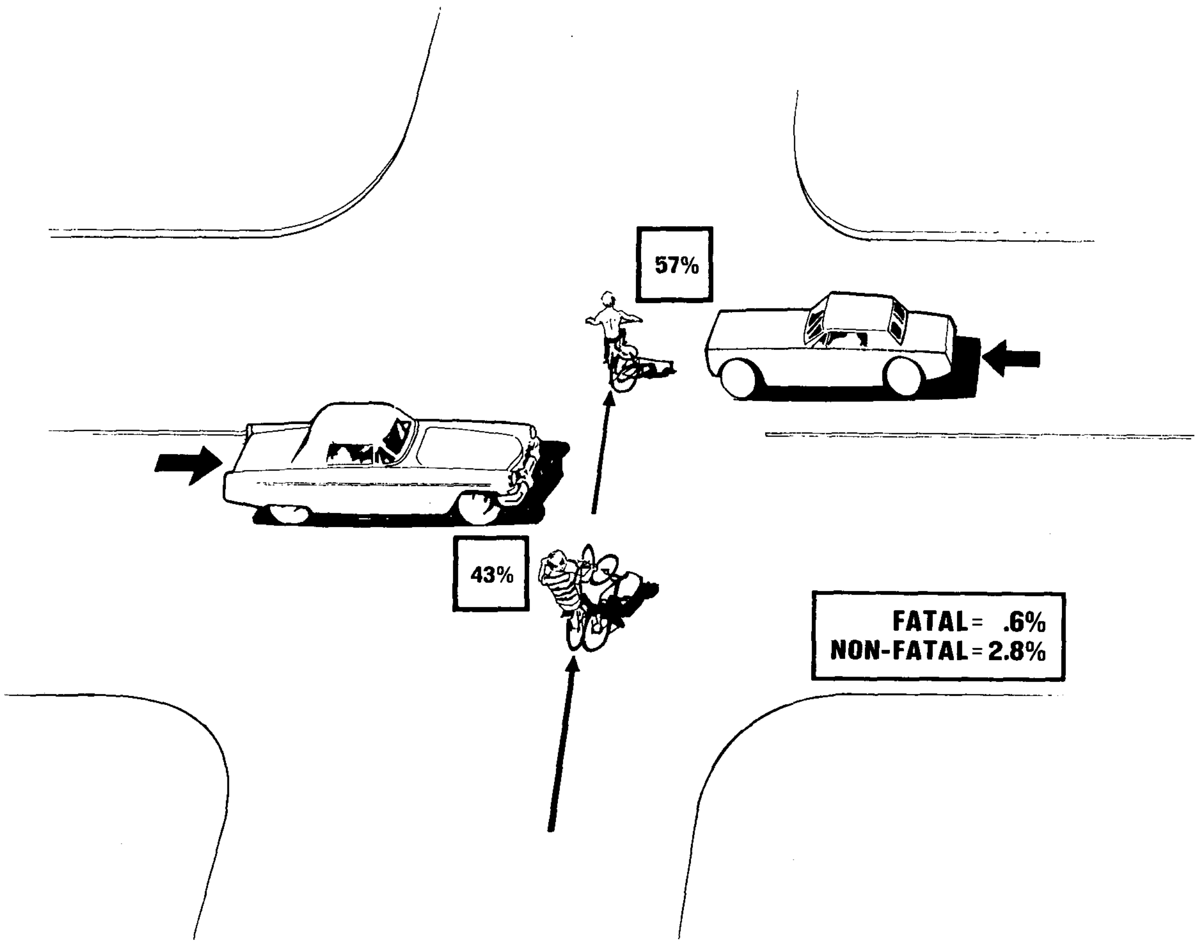


Figure 50. Illustration of Problem Type 25, *Vehicles Collide at Uncontrolled Intersection: Orthogonal Paths.*

vehicles were the most common type of obstructing objects. Darkness and inadequate bicycle lighting prevented the motorist from detecting the bicyclist in about ten percent of the cases. The remaining cases involved either a search failure or evaluation failure by the motorist. In about 24% of the cases, the motorist failed to search in the direction of the bicyclist--usually because the bicyclist was traveling in an unexpected location (wrong-way riding). The motorist observed the bicyclist early enough to have avoided the accident in 19% of the cases. The motorist's failure to initiate evasive action was usually due to his faulty assumption that the bicyclist would slow or turn before entering the junction.

More than half the bicyclists failed to search effectively on their approach to the junction. Usually, the bicyclist's failure to search was due, in part, to distractions from game playing and interacting with a passenger or another bicyclist. About 19% of the bicyclists observed the motor vehicle early enough to have avoided the accident but incorrectly assumed the motorist would turn or slow before reaching the bicyclist's intended path. About ten percent of the cases were due to an action failure--usually due to faulty brakes or a skill deficiency in operating caliper brakes.

A substantial number of the bicyclists who were involved in accidents of this type were very young. The median age of the bicyclists was 12.4 years. Five percent were six years of age or younger, and only 25% were 14 years of age or older.

Problem Type 26 (2.4% Fatal; 3.6% Non-Fatal)

The accident cases classified into Problem Type 26 are highly similar to those classified into Class D (Motorist Overtaking/Overtaking Threat). The main difference is that all Type 26 accidents involved a wrong-way-riding bicyclist and, therefore, a head-on collision. Ninety-six percent of all Type 26 accidents occurred on a relatively narrow two-lane roadway; 55% of the accidents occurred in an urban area and 41% occurred in a rural area. Seventy-eight percent of the accidents occurred during the daytime.

Problem Type 26 contains five distinctly different subtypes; these subtypes are described briefly below. It should be noted that several of the subtypes of Problem Type 26 correspond closely to problem types within Class D.

- Bicyclist Detected by Motorist--The bicyclist was riding facing traffic and was located in or near the center of the traffic lane. The motorist observed the bicyclist approaching and slowed or stopped his vehicle. Because the bicyclist was scanning elsewhere, he rode into the front of the slow-moving or stopped motor vehicle. This subtype accounted for 18% of the Type 26 accidents.

- Bicyclist Not Detected by Motorist--The bicyclist was riding facing traffic but was located close to the edge of the roadway. The motorist failed to observe the bicyclist because of a search failure (three cases), degraded visibility conditions at night (five cases), or because an object obstructed his view (six cases). The motorist's view was obstructed by a parked or moving motor vehicle in three cases; an embankment along a curve obstructed the motorist's view in the remaining three cases. Fifty-two percent of the Type 26 accidents were classified into this subtype.
- Counteractive Evasive Action--When on a head-on approach, both operators evaded in the same direction. This subtype accounted for 11% of the Type 26 accidents.
- Motor Vehicle Control Failure--The operator permitted the motor vehicle to drift too far to the right on a curve (4% of Type 26).
- Bicycle Control Failure--The bicycle drifted/swerved too far to the right (15% of Type 26).

Most of the bicyclists involved in Type 26 accidents were juveniles. The median age of the bicyclists was 12.9 years; about 70% of the bicyclists were between six and 15 years of age.

Problem Type 27 (.6% Fatal; .9% Non-Fatal)

Problem Type 27 includes cases in which the bicyclist collided with the rear of a stopped or slow-moving motor vehicle. About 43% of the accidents were the result of a search failure by the bicyclist, and an equal number were due to the bicyclist's failure to anticipate a sudden reduction in the motor vehicle's speed. In 14% of the cases, the bicyclist was unable to stop because of a skill deficiency in manipulating the caliper brakes.

Problem Type 28 (1.8% Fatal; .8% Non-Fatal)

All Type 28 collisions were head-on and involved a motor vehicle that was traveling on the wrong side of the roadway. Two cases involved a motor vehicle that was out of control. The other cases occurred as follows:

- A truck offloading cement inched forward as a bicyclist approaching from straight ahead was preparing to swerve around the front of the truck.
- The motorist was leaving an unpaved area adjacent to the roadway and drove a short distance on the wrong side of the roadway.
- The motorist veered into the left lane when preparing to make a sharp right-hand turn.

Problem Type 29 (.6% Fatal; .8% Non-Fatal)

All Type 29 accidents occurred in a parking lot or another large open area (83% occurred in a commercial parking lot); the vehicles were traveling orthogonal paths in every case. Visual obstructions were a factor in about one-third of the cases. Otherwise, the accidents resulted from a search failure by one or both operators.

Problem Type 30 (.1% Non-Fatal; No Fatal)

Problem Type 30 includes accidents in which the vehicles collided head-on because both operators evaded in the same direction. Type 30 includes only the accidents that occurred on a roadway so narrow that neither vehicle can be said to have been traveling on the wrong side of the roadway.

Problem Type 31 (.6% Fatal; No Non-Fatal)

Problem Type 31 accidents (one case) occurred when a bicyclist cut a corner when turning left and collided with a motor vehicle approaching on an orthogonal leg of the intersection.

Problem Type 32 (.3% Non-Fatal; No Fatal)

Problem Type 32 includes cases in which the bicyclist swung too far to the left when making a high-speed right-hand turn. The bicyclist collided with a parked motor vehicle, a standing motor vehicle, or a moving motor vehicle located on the roadway onto which the bicyclist turned.

Problem Type 33 (.4% Non-Fatal; No Fatal)

Problem Type 33 is similar to Problem Type 31 except that Type 33 accidents resulted from the *motorist* (rather than the bicyclist) cutting a corner when making a left-hand turn.

Problem Type 34 (.1% Non-Fatal; No Fatal)

Problem Type 34 includes accidents in which the motorist swung wide when making a right-hand turn and collided with a bicyclist approaching the intersection on the roadway onto which the motorist turned. Problem Type 34 is the counterpart of Problem Type 32.

Problem Type 35 (.3% Non-Fatal; No Fatal)

Problem Type 35 includes accidents that occurred when a motorist drove into the path of an approaching bicyclist when exiting an on-street parking space (one case parallel-parking space and one case diagonal-parking space).

Problem Type 36 (1.1% Non-Fatal; No Fatal)

Problem Type 36 includes a variety of accidents termed "weird" because of the unusual circumstances that led to their occurrence. Examples include:

- Bicyclist fell while being towed by a motorcycle.
- Bicycle struck by object that fell from a truck.
- Bicyclist was pushed into motor vehicle's path by pedestrian.
- Motorist deliberately collided with bicyclist (hostile act).
- Motor vehicle was struck in the rear by another motor vehicle and pushed into the bicyclist's path.
- Bicyclist stopped in the center of a traffic lane to retrieve dropped object and was struck by a motor vehicle.

COUNTERMEASURE APPROACHES FOR CLASS G PROBLEM TYPES

The countermeasure approaches required to counter Type 25 accidents (vehicles collided at uncontrolled intersection) are similar to the countermeasure approaches suggested for the bicyclist driveout and motorist turn-merge/drive through accidents. Among the most important countermeasure approaches for Type 25 accidents are the removal of visual obstructions, increasing bicycle conspicuity (front-oblique view), and training to enhance the effectiveness of operators' search behavior.

The countermeasure approaches required to counter Type 26 accidents are also similar to the countermeasure approaches suggested by other problem types. The most important include: increased enforcement of laws governing wrong-way riding, prohibition of night riding on narrow rural-type roadways, devices to increase the nighttime conspicuity of the bicycle (front view), and bicyclist education and training to enhance bicyclist's inclination to search effectively.

Most of the remaining problem types within Class G are amenable to one or more of the countermeasure approaches that have been recommended earlier. Otherwise, Problem Types 27 through 36 occur too infrequently to warrant the development of unique countermeasures.

SECTION VI
CONCLUSIONS AND RECOMMENDATIONS

Many specific conclusions and recommendations have been presented throughout this report. The purpose of this section is to describe the more general conclusions and recommendations drawn from this study and to reiterate the specific conclusions and recommendations considered most germane for programming further work to reduce the bicycle/motor-vehicle accident problem.

GENERAL CONCLUSIONS

MAGNITUDE OF THE PROBLEM

Accidents involving a bicycle and a motor vehicle represent an important problem in most communities within the United States. Each year since 1972, about 1,000 fatal and 40,000 injury-producing bicycle/motor-vehicle accidents are reported to the police. In addition, it is estimated that at least 40,000 injury-producing accidents go unreported each year. The property damage resulting from bicycle/motor-vehicle accidents is small in comparison to the property damage resulting from most other types of motor-vehicle accidents. Even so, it is estimated that the annual cost of property damage resulting from bicycie/motor-vehicle accidents exceeds three million dollars each year.

Based upon the injury data compiled during this study, the average bicyclist involved in a *police-reported* bicycle/motor-vehicle accident suffers the following consequences:

- 1.4 days in the hospital
- 1.4 days in bed at home
- 4.3 days missed work or school
- 23.6 days suffering pain or discomfort

REPRESENTATIVENESS OF THE SAMPLE

The samples of fatal and non-fatal accident cases compiled during this study are considered to be reasonably representative of *police-reported* bicycle/motor-vehicle accidents that occur throughout the United States. Furthermore, the set of problem types identified during the course of this study are considered both representative and exhaustive. That is, it is concluded that (a) the problem types reported here occur with about the same frequency in most areas throughout the United States and (b) there are few bicycle/motor-vehicle accidents that are so unique that they could not be classified into one of the 36 problem types reported here. No evidence was found that the causes of a given problem type differ in any important way from one geographical area to another. This is not to say, however, that the various contributory factors are equally common for all geographical areas.

When attempting to generalize the results of this study to a small or homogeneous area, two facts must be kept in mind. First, the sampling plan for this study was specifically designed to include accidents that occurred in a variety of area types, including: rural areas, small communities, and large metropolitan areas. Second, it must be kept in mind that some problem types occur far more often in some types of areas than others. For these reasons, the results of this study cannot be assumed representative of the bicycle accidents that occur within any one small or homogeneous area. The data available in Appendix D-3 must be used when attempting to extrapolate the results of this study to a specific type of area that is different from the sampling areas for this study. For instance, if a reader wishes to estimate the proportion of urban accidents accounted for by a given problem type, he should refer to Appendix D-3 to determine the number of accidents of that type which occurred in an urban area and divide this number by the number of *urban* accidents in the total sample.

FINALITY OF THE ACCIDENT CLASSIFICATION SYSTEM

A major conclusion of this study is that there are several potential functional groupings of accident cases that are optimal for the identification of all types of countermeasure approaches. A functional grouping that is best for the identification of engineering countermeasures is not optimal for the identification of educational countermeasures; a functional grouping that is best for identifying engineering countermeasures is not optimal for the identification of enforcement countermeasures; and so on. As a result, the classification system presented here is only one of many that could have been developed from the same data base. The authors believe that the classification system that is described in Section V serves the purpose for which it was designed. However, it is recognized that special interest groups (engineers, educators, etc.) may find that a different grouping of accident cases would have suited their purposes better. An attempt has been made to provide the data that readers may need to reorder the classes, types, or subtypes in a more useful fashion and to estimate the frequency of occurrence of the new "problem types" that are defined in this manner.

ACCIDENT CAUSES

Another major conclusion of this study is that the causes of the vast majority of bicycle/motor-vehicle accidents are behavioral. In well over 60% of the cases, the bicyclist's pre-crash course was suboptimal, indicating that a predisposing or precipitating error was made before the other vehicle could have been observed. The motorist's pre-crash course was suboptimal in about one-fifth of the cases. The implication of this finding is that countermeasures for a substantial portion of the accidents must focus on the operator's pre-crash course, rather than on his responses at the time the other vehicle first becomes observable.

When there was sufficient time to have avoided the accident once the other vehicle first could have been observed, the accident was usually precipitated by a search or evaluation failure by one or both operators.

The results indicate that most of the function failures by motorists were the type that would be committed by most motorists who found themselves in a similar situation. Conversely, the function failures committed by bicyclists were most often behavioral errors in the true sense of the word. That is, the function failures represented errors that would seldom be committed by a reasonably knowledgeable and safety-conscious bicyclist. Therefore, another general conclusion drawn from the results of this study is that few motorists' function failures and most bicyclists' function failures represent aberrant behavioral errors. This general conclusion does not apply to intoxicated motorists. It can also be concluded that aberrant behavioral errors are far more common among juvenile than adult bicyclists. Except for intoxication, the operators' behavioral errors are seldom the result of a temporary or permanent impairment.

Contrary to popular beliefs, bicycle/motor-vehicle accidents are seldom the direct or indirect result of roadway-surface defects, debris on the roadway surface, sewer grates, bicycle defects or failures, motor-vehicle defects or failures, riding double, bicycle too large or too small for the operator, bicycle-handling skill deficiencies, hostile acts by motorists, high risk acceptance by bicyclists, or the bicyclist's deficient knowledge of traffic laws and ordinances. The non-behavioral factors that are the most important contributors to bicycle/motor-vehicle accidents include: visual obstructions, narrow roadways (selected locations), darkness, daytime and nighttime conspicuity of bicycles, and the vertical dimension of the bicycle/bicyclist unit.

COUNTERMEASURE APPROACHES

Two important conclusions are apparent from a study of the countermeasure approaches that were identified for individual problem types. First, nearly every problem type is amenable to several altogether different countermeasure approaches. Second, many of the specific countermeasures that were identified have the potential for effecting a reduction in several different problem types. In short, most problem types have more than one potential solution and most solutions apply to more than one problem type. It is essential that these facts be considered when performing the trade-off analyses required to develop a cost-effective countermeasures program.

It cannot be concluded that the set of countermeasure approaches identified in this report is exhaustive, nor can it be concluded that any specific countermeasure suggested herein will prove to be cost-effective. It would be pretentious for any small group of individuals to assume they are capable of identifying all, or even most, solutions to such a complex problem as bicycle/motor-vehicle accidents. It would be both surprising and disappointing if the readers of this report did not identify many innovative solutions that simply did not occur to the authors and their colleagues. Some countermeasure approaches were listed even though they appeared impractical. These countermeasures were listed with the hope that they would stimulate ideas about variations of the approach that *would* prove practical.

Many of the countermeasure approaches that were suggested are so general that they resemble problem definitions more than problem solutions. Hopefully, these general countermeasure approaches will serve to focus the research and development community's attention on the most germane problems and issues.

RECOMMENDATIONS

PROGRAMMATIC RECOMMENDATIONS

Dissemination of Information

The results of this study show that many of the current beliefs about the causes of bicycle/motor-vehicle accidents are erroneous. These erroneous beliefs currently are resulting in the expenditure of time and resources on remedial programs that have little potential for accident reduction. For this reason, it is recommended that a program be developed to disseminate information about the problem types to individuals and agencies who are involved in developing or implementing bicycle-safety programs. The groups that should be given highest priority include: educational institutions, law enforcement agencies, transportation planning organizations, parent/teacher organizations, bicycle clubs, public service organizations, bicycle manufacturers, and concerned governmental agencies at all levels.

Evaluation and Refinement of Countermeasure Approaches

The Office of Driver and Pedestrian Research, National Highway Traffic Safety Administration, presently has a program underway which will enable a multi-disciplinary team of experts to study the problem types in detail, evaluate the countermeasure approaches suggested in this report, attempt to identify other innovative countermeasure approaches, and formulate recommendations about specific countermeasures that should be developed and evaluated. It is recommended that local and state agencies and special-interest groups be encouraged to engage in a similar activity but focus on the problems and constraints present within a specific state, county, or community. In addition to the identification of unique and innovative countermeasures, such an activity would have great educational value for those involved.

Implementation of Selective Enforcement Program

It is recommended that communities throughout the country be urged to develop and implement a selective enforcement program which focuses on critical violations by specific bicyclist target groups. The critical violations include: entering the roadway from a driveway or alley without slowing, stopping, or searching for traffic (local ordinances will be required to make this action unlawful); riding on the wrong side of the roadway; failure to stop for stop signs; entering a signalized intersection during an amber signal phase (additional regulations may be required); and turning without signaling or searching for traffic. The target population for the selective enforcement program is mainly juveniles. A more specific description of the target population for each of the critical violations is presented in Section V.

REQUIREMENT FOR ADDITIONAL RESEARCH

Bicyclist Behavior

There are at least three germane questions about accident causation that were not fully answered by this study. One of the most critical questions concerns the role of hazard recognition and risk assessment in juveniles' selection of a non-optimal course and their failure to search in critical situations. Research is needed to (a) identify the features in the environment that represent obvious cues to hazard for adult bicyclists, but either are not perceived or are not correctly evaluated by juveniles; and (b) identify the environmental features that juvenile bicyclists consider when assessing the risk associated with a specific behavioral act at a specific location.

A second important question that remains unanswered concerns the reasons why juvenile bicyclists fail to search to the rear before initiating a left-hand turn. Research is needed to (a) evaluate bicyclists' capability to maintain control of their bicycles when scanning to the rear, (b) determine the extent to which this specific skill can be enhanced through training, (c) determine the extent to which bicyclists rely on auditory cues to detect overtaking motor vehicles, and (d) identify the traffic contexts in which bicyclists tend to rely on auditory cues.

A third question concerns the manner in which a bicyclist's behavior changes when riding with a companion--particularly when the bicyclist is following his riding companion. Many bicyclists reported that their selection of a suboptimal course and their failure to search for hazards was due to their assumption that the lead bicyclist would perform these tasks. It is likely that this behavior pattern is more common than was reported by the bicyclists. Research is needed to (a) determine the manner in which a bicyclist's behavior changes when he is trailing another bicyclist and (b) assess the absolute frequency with which this "blind following" behavior contributes to accident-producing actions by the trailing bicyclist.

Bicycle Modifications

Developmental research is required to (a) create devices that will increase the vertical dimensions of the bicycle, and thereby increase the likelihood that it will be observed when partly obscured by parked motor vehicles and other low-lying objects; (b) create devices to increase both the daytime and nighttime conspicuity of bicycles; and (c) create rear-vision devices for bicyclists that are effective, safe, and acceptable to the bicycle-user population.

Education and Training

It is anticipated that a considerable amount of research will be required to define the most cost-effective methods for imparting the requisite knowledge and skills to the various parties who would benefit from education and training. Research on the education and training of bicyclists and motorists should receive the highest priority.

Regulations and Enforcement

Research is required to assess the feasibility of selective prohibitions, including: (a) prohibiting bicycle riding on specific types of roadways; (b) prohibiting riding during specific times of the day or night (general, or at specific locations); (c) prohibiting riding by bicyclists younger than a specified age; and (d) prohibiting riding until bicyclists are able to demonstrate specific knowledge and skills. Research is also required to identify effective deterrents for the critical violations.

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